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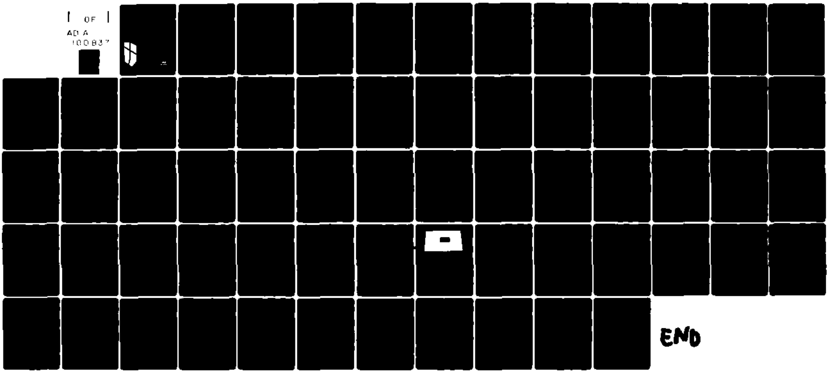

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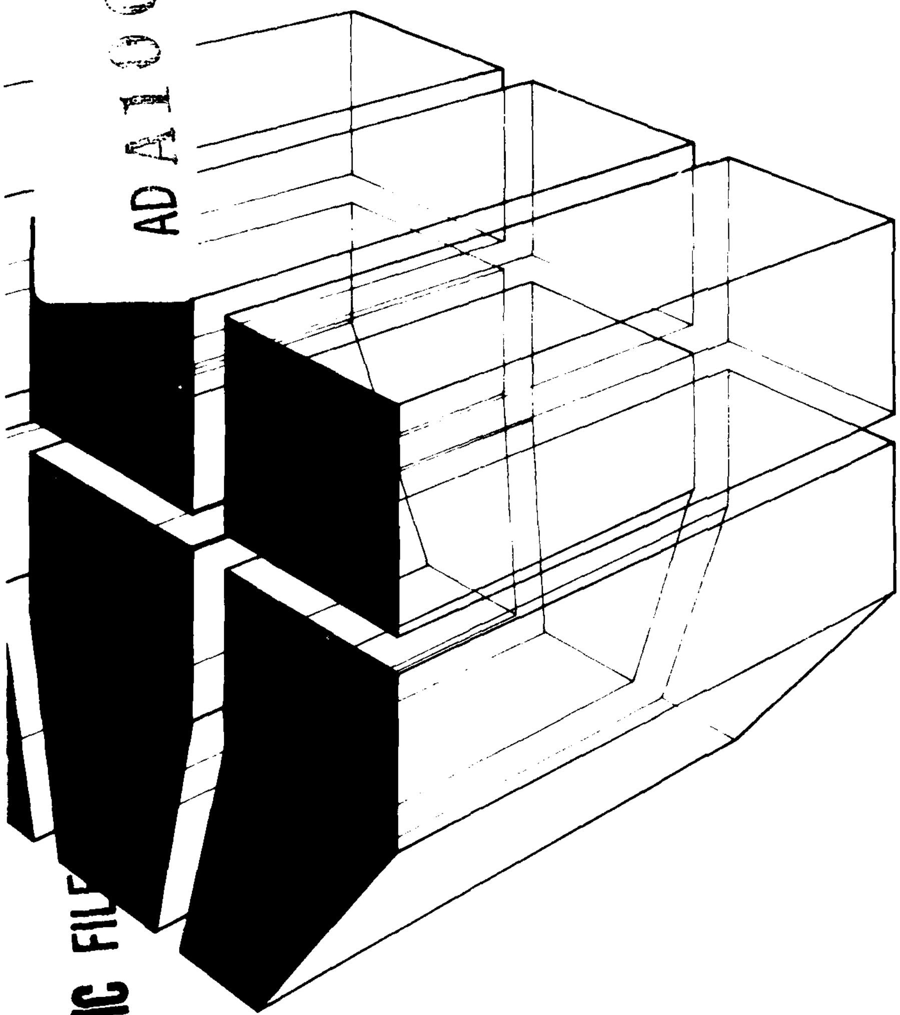
May 1981

ELECTRICAL ENERGY REDUCTION FOR ARMY INSTALLATIONS



by
L. M. Windingland

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This report describes an analysis of electrical energy consumption of selected Army buildings at representative Army installations and of methods that can be used to reduce electrical consumption and associated utility costs at these installations. The report defines various techniques such as power factor correction, lighting reduction, motor voltage controllers, and the benefits derived from their application. The report shows that electrical

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consumption is significant when the buildings are unoccupied; in fact, the unoccupied consumption, especially in administration, maintenance and operations buildings, often amounts to over 60 percent of total annual consumption. It was concluded that a detailed, building-by-building electrical reduction program employing intelligent and more effective use of heating, ventilating, and air conditioning equipment scheduling, motor control, and reduced lighting will provide the most cost effective electrical consumption reduction.

A

FOREWORD

This work was performed for the Directorate of Military Programs, Office of the Chief of Engineers (OCE) under project 4A762731AT41, "Design, Construction and Operation and Maintenance Technology for Military Facilities"; Technical Area B, "Operation and Maintenance of Fixed Facilities"; Work Unit 025, "Utilities Management." Mr. Homer Musselman, DAEN-MPO-U, was the OCE technical monitor.

The work was performed by the Energy Systems Division (ES) of the U.S. Army Construction Engineering Research Laboratory (CERL). Mr. R. G. Donaghy is Chief of ES. Appreciation is expressed to Mr. B. Sliwinski, Mr. W. D. Ford, and Mr. L. Thurber of CERL for their assistance in data gathering and device testing, and to the Facilities Engineering personnel at Fort Carson, particularly Mr. Frank Florian, Mrs. Pat Espander, and Mr. Ron Wilhelm, for their assistance and timely support.

COL Louis J. Circeo is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

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ELECTRICAL ENERGY REDUCTION
FOR ARMY INSTALLATIONS

1 INTRODUCTION

Background

Since the energy crisis of 1973-74, the continually increasing cost of electricity has adversely affected Army installation operations and budgets, and has become a subject of concern to installation commanders, Major Commands (MACOMs), and the Office of the Chief of Engineers. Since 1975, the Army's electricity expenditures have increased by 61 percent. In FY79, the Army used 7,791,000 MWh of electricity at a cost of $290 million;[1] this represented a 3 percent increase over 1978 use and more than 5 percent increase over FY78 expenditures. In addition, this figure represents nearly 38 percent of the Army's total expenditures for utility services. Therefore, electricity consumption is a significant Army expenditure in terms of both dollars and energy. Although Facility Engineers (FEs) and MACOMs have been directed to reduce electrical energy consumption,[2] they have not yet realized major savings because there is a lack of knowledge about where energy is consumed and about specific reduction measures.

In a previous study the U.S. Army Construction Engineering Research Laboratory (CERL) analyzed the electrical energy consumption of several representative Army installations.[3] General information was obtained about the amount of electricity consumed by equipment components. Electrical energy end-use consumption was then determined, and the effects of occupant activities and lifestyles on electrical energy consumption were evaluated. Installation procedures and techniques that were being used to reduce electrical energy consumption on installations were also observed and evaluated, and a checklist for FEs to use when inspecting buildings was developed to eliminate electrical energy waste. This information and the information documented in this report will be used to reduce electrical energy consumption on installations, and thus reduce overall Army expenditures.

Objective

The objectives of this study are (1) to provide a detailed description of how electrical energy is being used on military installations for both lighting and building components, (2) to describe daily and seasonal changes in

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1 Facilities Engineering, Annual Summary of Operations (Department of the Army, Office of the Chief of Engineers, FY75, FY76, FY77, FY78, and FY79).

2 Army Energy Plan, ADA057987 (Department of the Army, 24 February 1978); Army Facilities Energy Plan (Department of the Army, 1980).

3 L. Windingland, An Analysis of Electrical Consumption at Representative Army Installations, Interim Report E-163/ADA085298 (U.S. Army Construction Engineering Research Laboratory [CERL], May 1980).

electrical consumption and the relation to billing procedures, and (3) to suggest operational changes, equipment, and techniques to reduce electrical energy consumption on Army installations.

Approach

A detailed analysis of electricity consumption by various installation components was conducted.

Daily and seasonal electrical power demands and the power cost/billing structure were analyzed to determine potential for savings through reduction of peak electrical demand.

Tests were performed on various types of equipment to determine their potential for saving electrical energy.

Recommendations for retrofit opportunities and/or probable operational changes that would reduce electrical energy consumption were prepared.

Mode of Technology Transfer

Information from this study will be used to prepare an Engineering Technical Note detailing recommended methods and procedures for reducing electrical energy consumption on Army installations.

2 DISCUSSION

General

The Army has experienced major increases (60 percent) in the cost of electrical energy since FY75. The cost has risen from $181 million in FY75 to $290 million in FY79, while annual consumption has decreased 3.3 percent -- from 8.058 billion kWh to 7.791 billion kWh.[4] Thus, it is quite apparent that cheap and plentiful energy is no longer available. FEs must now seek methods and procedures to lower electrical energy consumption and expenditures.

Installation commanders, FEs, and utility managers who budget and manage the use of electrical energy are well aware of the rising costs. Most FEs have attempted to reduce consumption on their installations by methods such as changing exterior lighting systems or reducing lighting levels; however, few have achieved substantial overall installation savings. As new facilities are added to the installation, the buildings they are to replace are sometimes temporarily used for other purposes; this increases the post's total area and subsequently increases electrical energy use. In addition, the new buildings often consume more energy than the ones they replace because of their more sophisticated and complex heating, ventilating, and air-conditioning (HVAC) systems (e.g., electrically driven fan-coil units in each room vs. steam/hot water radiators). Increased use of flight and ground equipment simulators, additions of computers, electric typewriters, refrigerators in barracks, and electric heat pumps for family housing also increase an installation's electrical use. Though they may result in substantial overall energy savings (e.g., simulators save vast amounts of aviation fuel), these factors make reduction of electrical energy consumption extremely difficult. Some of these factors cannot be eliminated easily, but several methods and equipment, if properly applied, can produce substantial electrical energy and cost savings.

Installation Consumption

Army installations normally purchase their electrical energy from local utility companies. High-voltage electrical energy is provided to substation transformers through appropriate protective electrical devices and then distributed at a lower voltage; for example, 12.47/7.2 kV on overhead or underground distribution feeders to various sections of the installation. The final transformation to a usable facility/building voltage, for example, 120 or 480 V, is provided by secondary distribution transformers between the feeder and the facility/building requiring the electrical energy.

A CERL study conducted in FY77 through FY79 at Fort Carson, CO, determined where purchased energy was being used on the installations. Submetering of distribution feeders was analyzed to determine trends and evidence of high-use areas.[5] The initial analyses, which considered monthly total consumption by feeder, were inconclusive because feeder consumption patterns were

[4] Facilities Engineering, Annual Summary of Operations (Department of the Army, Office of the Chief of Engineers, FY75, FY76, FY77, FY78, and FY79).

[5] L. Windingland, An Analysis of Electrical Consumption at Representative Army Installations, Interim Report E-163/ADA085298 (CERL, May 1980).

inconsistent, and because no evidence of trends could be obtained. However, analyses of daily and hourly consumption data showed that a major portion (more than 60 percent) of electrical energy is consumed on a continuous basis. It can be seen from Table 1 that many of the buildings (57 percent) served by the feeder would be totally unoccupied at night. However, electrical data indicate some of these are being operated as if they were occupied. This consumption occurs continuously every hour of every day, forming a major portion of the total feeder consumption. Figure 1 shows an example in which the minimum hourly demand was 470 kW and total consumption for that period was 447,300 kWh. In this case, the minimum hourly demand (470 kW x 24 hours/day x 25 days divided by the total consumption -- 447,300 kWh) is equal to 0.63, or 63 percent of the total. The area under the curve bounded by the minimum demand consists of 63 percent of the total area under the curve.

Installation electrical energy uses are closely related to those of small municipal operations, including: building operation (i.e., lights, appliances, fans, pumps, chillers, cooling towers, water heaters), street lighting, security and safety lighting systems, traffic control systems, communications equipment, computers, maintenance activities, recreational lighting, water pumping and distribution, sewage collection and treatment, refrigeration for cold storage, airfield lighting, snow melting, ice removal, and cathodic protection. In addition, some energy is lost as heat due to transformer and

Table 1

Facilities Served by Feeder

Type	Square Feet	% of Total Square Feet
Administrative	213,100	17.3
Training	32,500	2.7
Operational/Maintenance	32,400	2.6
Medical/Dental Clinics	236,900	19.3
Hospital	168,000	13.7
Recreational:		
Night Operation	131,000	10.6
Day Operation	87,000	7.2
Troop Housing	198,900	16.1
Family Housing	36,300	2.9
Storage	94,000	7.6
Total	1,230,100	

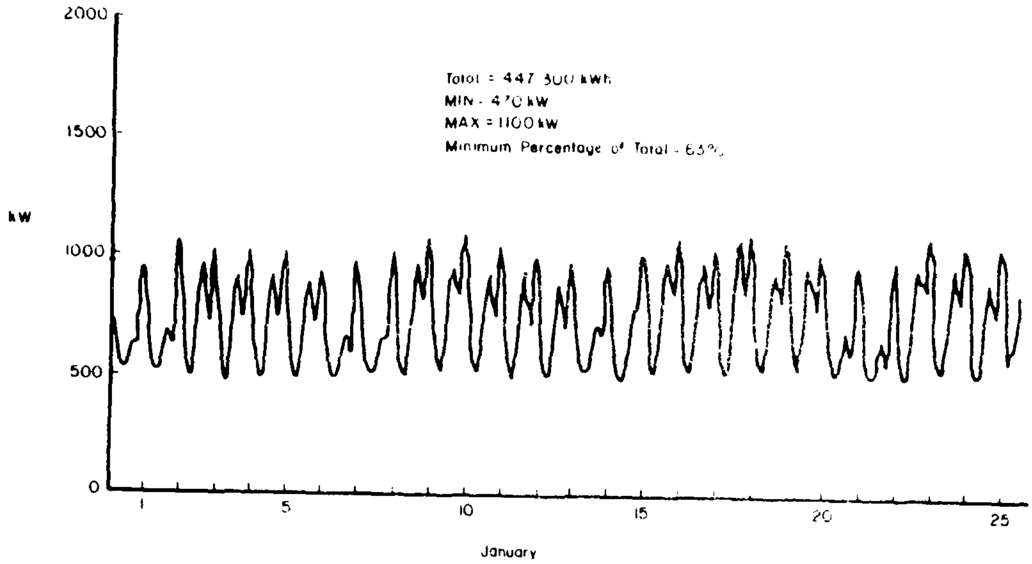

Figure 1. Monthly feeder profile.

distribution losses that occur as electricity is distributed throughout the installation.

Electrical Costs

The average cost of a kWh of electrical energy varies by installation, ranging from 0.8 cents/kWh to 7.6 cents/kWh. The most realistic method of comparing electrical energy costs is to divide the total expenditures by the number of kWh used over a consistently spaced period of time that will produce valid comparisons. However, these results must be applied with caution. A monthly comparison, preferably for a year, may reveal considerably different costs per kWh for a particular installation. Depending on the utility rate structure, the cost can vary by month and even by time of day. Utility contracts contain several different billing items, as well as the amount of energy consumed. Some of these costs are obvious, while others may be partially hidden.

The cost of electrical energy was analyzed by comparing the rate structure and utility bills at Army installations with the incremental costs of major items on electrical utility bills (energy, fuel adjustment, demand, and power factor charges). Tables 2 and 3 show these costs. This information will enhance utility bill analysis and thus in some cases assist in determining the most cost-effective rate structure for the installation and clarify hidden costs in the utility bills. Some utilities which serve Army installations have only one government rate schedule, resulting in a no-choice situation.

Table 2

1978 Itemized Electrical Cost

Month	Energy K$	Energy %	Fuel Adjustment K$	Fuel Adjustment %	Demand K$	Demand %	Power Factor K$	Power Factor %	Total
Jan	96.1	71	7.3	5	31.9	24	--	--	135.3
Feb	90.1	69	7.4	6	32.3	25	--	--	129.8
Mar	78.7	67	6.5	6	31.9	27	--	--	117.1
Apr	84.0	71	4.9	4	29.1	25	--	--	118.0
May	78.7	68	5.7	5	30.7	27	0.5	0.4	115.5
Jun	76.5	59	19.0	15	31.7	25	1.6	1.2	128.8
Jul	88.3	59	25.9	17	31.9	22	2.3	1.5	148.4
Aug	88.9	62	17.7	12	32.6	23	3.2	2.2	142.5
Sep	80.6	58	24.8	18	31.0	22	2.2	1.6	138.5
Oct	77.9	61	19.8	15	29.4	23	0.4	0.3	127.5
Nov	84.2	61	20.9	15	31.3	23	0.6	0.5	137.0
Dec	92.4	62	25.2	17	30.3	20	0.8	0.5	148.8
Annual	1,016.4	64	185.1	11.7	374.1	23.6	11.6	0.7	1,587.2

Table 3

1979 Itemized Electrical Costs

Month	Energy K$	Energy %	Fuel Adjustment K$	Fuel Adjustment %	Demand K$	Demand %	Power Factor K$	Power Factor %	Total
Jan	87.4	66	14.1	11	31.0	23	0.7	1.0	133.3
Feb	84.2	62	19.1	14	31.0	23	0.6	0.5	134.9
Mar	76.3	63	14.9	12	30.3	25	0.3	0.3	121.8
Apr	84.8	69	7.8	6	28.7	23	1.1	1	122.3
May	76.7	63	16.0	13	29.4	24	0.5	0.4	122.6
Jun	76.3	55	31.9	23	29.4	21	1.4	1	139.0
Jul	78.5	58	22.8	17	31.3	23	1.8	1.3	134.4
Aug	79.9	59	21.2	16	31.7	23	2.1	1.6	134.8
Sep	82.5	57	30.2	21	30.7	21	1.7	1.2	145.1
Oct	78.8	56	31.9	23	29.4	21	1.1	0.8	141.2
Nov	79.1	56	29.9	21	31.3	22	1.0	0.7	141.3
Dec	86.5	58	32.3	22	30.0	20	0.1	0.1	149.1
Annual	971.0	60	272.1	16.8	364.2	22.4	12.4	0.8	1,619.8

Building Electrical Consumption

During FY79, 20 Army buildings were selected for analysis, including bachelor quarters, an administration building, dining facilities, a dental clinic, a theatre, an officers' open mess, and maintenance facilities. The total consumption by month for the 20 buildings for 2 years was determined from metered electrical energy data. The air-conditioning baseline load (minimum demand), peak demands, seasonal changes in electrical energy use, and evidence of increase and decrease in electrical consumption were identified for each building. These data were presented in CERL Interim Report E-163.[6] This report indicated that the majority of the buildings' electrical energy consumption occurred during nonduty or nonoccupied hours. Often, the annual unoccupied consumption consisted of over 75 percent of the facility's total annual consumption. This indicates the additional electrical energy to support occupancy may be as little as 25 to 40 percent of the total building consumption. These data supported a conclusion that substantial emphasis should be placed on reducing the building's minimum baseline electrical energy consumption. This would provide savings every hour of the year, as well as reduce peak demands. Some items to consider for savings are the air handling motors, hot water heaters, and circulating pumps used in unoccupied buildings.

Breaking out electrical energy consumption by air conditioning, heating, lighting, appliances, and miscellaneous electrical energy use provided a more detailed analysis for a barracks, a dental clinic, and an administration building. The baseline consumption data, along with operational information, show where major savings can be achieved for each building.

Reduction Equipment and Techniques

A literature search was performed to determine new equipment and proven techniques for reducing electrical energy consumption. Detailed information was obtained on devices improving operating characteristics of motors, lighting, electronic time switching, and energy management and control systems. Items that can have near time effects on building electrical consumption were analyzed, as well as how to apply them to obtain maximum benefits. Based on this analysis, Chapter 3 lists techniques that the FE can use to minimize electrical energy consumption within facilities while still maintaining occupant comfort.

Specific Tests

CERL performed laboratory tests on fluorescent light fixtures to determine the energy-conservation effects of low-consumption lamps, high-efficiency ballasts, and the effect of removing tubes with and without disconnecting ballasts (pp 23-30). A power factor controller was tested to determine cost effectiveness at various motor loadings and to define a method of applying these devices to Army uses (pp 50-53).

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[6] L. Windingland, An Analysis of Electrical Consumption at Representative Army Installations, Interim Report E-163/ADA085298 (CERL, May 1980).

Field tests were performed on low-consumption fluorescent lamps to determine the measured effect of group relamping, and on programmable multifunction time switches to control HVAC motors and equipment in an Army building (pp 43-45).

3 OBSERVATIONS OF ELECTRICAL CONSUMPTION AND COSTS

Installation Consumption

The profile for electrical demand shown in Figure 1 for one of the feeders at Fort Carson, CO, is for a winter month, and therefore does not include the air-conditioning demands. Substantial variations in hourly consumption occur throughout a day, ranging from a minimum of 470 kW to a maximum of 1100 kW. The variations between weekdays and weekends can be more clearly noted from Figure 2.

The total connected transformer capacity on this circuit is 3280 kVA, of which 187 kVA is the connected transformer capacity of street lighting circuits. The minimum hourly consumption, extended over the number of hours shown on the curve, constitutes 63 percent of the total feeder consumption. The feeder serves 63 buildings.

Figure 2 is a plot of the hourly consumption for a winter weekday and weekend day. These data show that maximum demand occurs at about 1900 hours in the evening, and that minimum demand occurs at 0300 hours in the morning. The data show the increasing consumption at the beginning of a workday and the increase, due to exterior and street lighting, at roughly 1800 hours. It is interesting to note that the difference in total consumption between a weekday and a weekend day is only 11 percent. The majority of the buildings (see Table 1) served by the feeder should not be in use on the weekend (e.g., administration, training, and maintenance).

A study of the data indicates that street and exterior lighting account for 15 to 25 percent of the minimum nighttime consumption. The primary reason

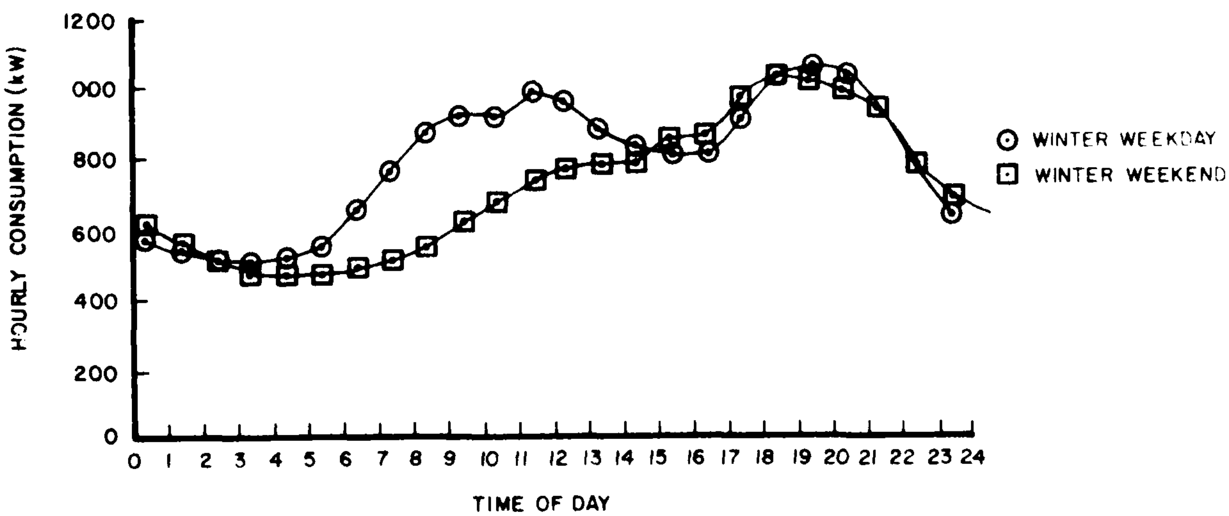


Figure 2. Daily feeder profile.

for the high minimum demand (470 kW) is the continuous operation of heating, ventilating, hot-water heating, and pumping equipment within the buildings. This is estimated to be 60 to 70 percent of the minimum. Other contributions to the baseline minimum are refrigerated storage, security and safety lighting, vending machines, water coolers, clocks, and emergency lighting system rechargers. It is also assumed that some electrical energy is being consumed by lights and appliances being used late at night or negligently left on by building occupants.

Although this profile shows only one feeder at Fort Carson, other feeders on the installation exhibit the same general profile and similar minimum hourly consumption rates. Complete data for these feeders were presented in CERL Interim Report E-163.[7] Figures 3 and 4 show the distribution of the electrical consumption, by building, at Forts Carson and Belvoir. These charts were extracted from CERL Interim Report E-143.[8] Information for the charts was derived from a regression analysis of electrical consumption data for several buildings in each of the consumer groups (i.e., family housing, troop housing, maintenance) and from data obtained from the installation real property inventory. The charts show that the buildings consuming the most electricity per unit area are community facilities, medical-dental facilities, and administrative and training buildings, while the major post electrical consumers are administrative and training, family housing, and community facilities. The charts represent only the portion of electricity consumed by the buildings; however, other installation electrical uses such as street lighting, water and sewage distribution and treatment, and refrigerated storage also represent a significant portion of total annual consumption. Chapter 4 gives a breakdown of electrical energy consumption within buildings

Electrical Energy Costs

An electrical energy cost analysis for a large user like an Army installation is not as straightforward as it may seem. Individual household electrical bills usually include a basic charge for the connection, a charge for the amount of energy used, and an adjustment charge to compensate the utility for higher fuel prices. On the other hand, large users often have additional charges, such as demand and power factor penalties, which can add substantially to the total electrical utility bill. The following sections analyze these costs.

Energy

The electrical energy consumed by an installation is partially billed by amount of energy used in kilowatt hours, as calculated from differential readings of the utilities' master electrical meter. When the meter is read, the previous month's reading is subtracted from the current reading and the difference multiplied by an appropriate meter factor to obtain the total

7 L. Windingland, An Analysis of Electrical Consumption at Representative Army Installations, Interim Report E-163/ADA085298 (CERL, May 1980).

8 B. Sliwinski, D. Leverenz, L. Windingland, and A. Mech, Fixed Facilities Energy Consumption Investigation -- Data Analysis, Interim Report E-143/ADA066513 (CERL, February 1979).

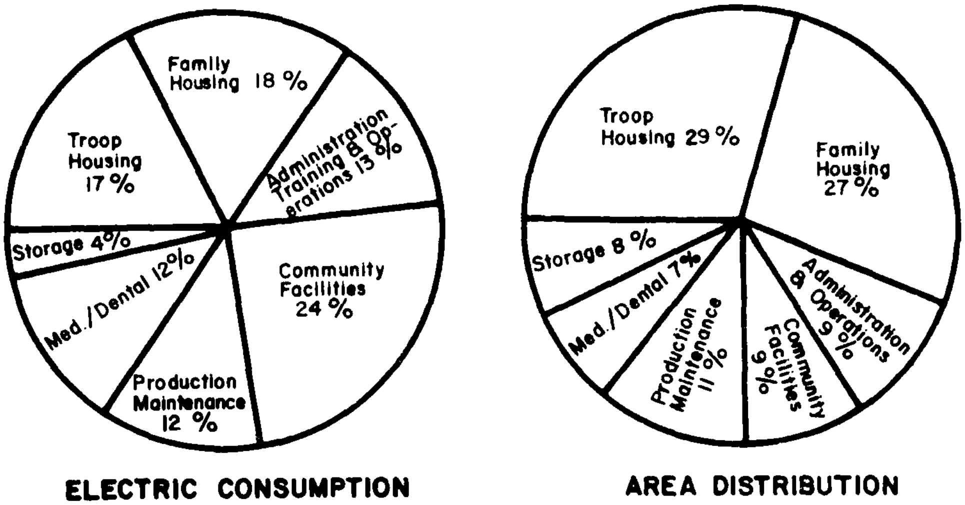


Figure 3. Electrical consumption and area distribution -- Fort Carson.

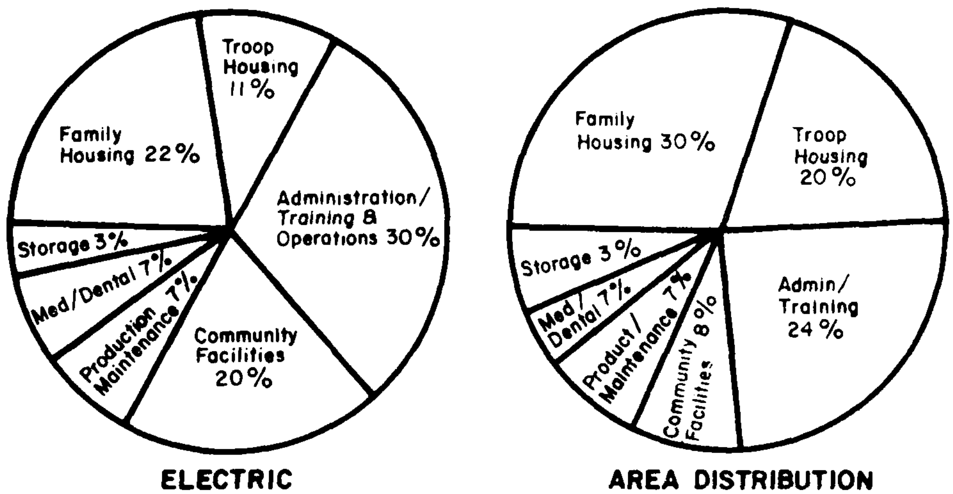


Figure 4. Electrical consumption and area distribution -- Fort Belvoir.

kilowatt hours consumed. The rates for electrical use, although sometimes a flat contract amount per kilowatt hour (e.g., \$0.03/kWh), often depend on the amount of energy consumed, with a higher rate for an initial predetermined amount, and a decreasing rate when consumption exceeds this initial amount. For example, the first 100,000 kWh may be billed at \$0.023/kWh and any amount beyond that billed at \$0.016/kWh. The energy consumption costs (\$/kWh) on an Army installation typically represent about 40 to 65 percent of the total electric utility bill.

Electrical consumption can also be billed in this manner on a kWh/kW demand basis. An example of this rate structure would be the first 200 kWh/kW demand at $0.023/kWh, the next 200 kWh/kW demand at $0.016/kWh, and all additional kWh at $0.014/kWh. This type of structure increases the rate per kWh based on the highest demand for electricity during that period; for example, if consumption for a facility were 10,000 kWh, and the demand were 20 kW, the bill would reflect a total cost of $0.0184/kWh, and if the maximum demand were 25 kW, the total cost would be $0.0195/kWh. In the first case, 4000 kWh would be billed at $0.023/kW, the second 4000 kWh at $0.016/kW, and the remaining 2000 at $0.014/kW. In the second case, the first 5000 kW would be billed at $0.23 and the remaining 5000 would be billed at $0.016/kW.

In addition to energy charges, utility companies use fuel adjustment charges, which fluctuate primarily according to changing costs of the fuel used to generate electricity. For example, a fossil fuel cost adjustment for one Army installation reads as follows: "An amount equal to 1.07 times the portion of system input represented by steam generation times the difference between the actual unit cost of fuel burned during the second month preceding the date of billing and a base unit cost of $0.04836/kW of net steam generation. The actual unit cost of fuel burned shall be determined by dividing actual monthly costs of oil, gas, and coal burned by the total system steam generation exclusive of station power; an amount equal to the product of monthly billing kWh times the unit fuel adjustment is the total fuel adjustment charge." Such a fluctuation can make utility budgeting extremely difficult, since this charge can range from 5 to 25 percent of a monthly utility bill.

Demand

Electrical demand charges are based on the highest rate at which electrical energy is consumed during a specific time period. The demand charge is designed to make the customer pay a share of the utility company's investment for the production, transmission, and distribution equipment necessary to meet maximum requirements. The electric utility company provides all of the power that an installation requires whenever power is needed. Thus the company must invest in enough equipment to supply the installation's peak power requirements even though these may occur for only a brief portion of a billing period. Therefore, the demand charge is intended to compensate the utility company for its investment and to encourage the customers to decrease power use peaks so that the utility company's equipment can be used most efficiently.

The installation's actual demand is computed as the average amount of energy consumed in a predetermined demand measurement interval -- normally 15 minutes (other intervals, such as 30 or 60 minutes, are also used by some utilities). Regardless of the interval, the highest demand recorded during a month becomes the billing demand for that month. Some utilities also employ a special clause, known as a ratchet clause, which states that no matter what the installation's actual demand may be in a given month, the demand for which the installation is billed will be no less than a certain percentage of the maximum monthly demand during a set number of immediately preceding months or of the maximum annual demand. Such a clause can penalize the installation for one 15-minute period in a year when the demand is greatest, even though that peak may never occur again; therefore, elimination of peaks could save a substantial amount of money for the entire year.

Demand charges vary from utility to utility, with typical charges ranging from $1 to $5 per kW or kVA. These charges are typically 20 to 40 percent of the total electrical utility bill (if kVA, an increase in power factor may also reduce demand).

Power Factor Charges

Power factor is a measure of the phase relationship between current and voltage in an alternating current electrical system. Under ideal conditions of purely resistive loads (rarely achieved), current and voltage are in phase, and the power factor is unity (1.0). If inductive loads (e.g., induction motors, transformers, or fluorescent lighting, arc furnaces, rectifiers, or welders) are part of the load, the power factor will be less than 1 (typically 0.8 to 0.95).

Generating and power distribution systems (except prime movers) owned by the electric utility company have their capacity measured in kVA, where kVA is equal to the voltage times the current (times $\sqrt{3}$ for three-phase) divided by 1000. With a unity power factor, it takes 2000 kVA of generating and distribution network capacity to deliver 2000 kW. However, if the power factor were 0.9, the generating and distribution capacity of the utility company would need to be 2222 kVA to deliver the same 2000 kW. Thus, low power factor adversely affects generating and distribution capacity.

Electric utilities almost always require that large users keep their power factor above a given value (e.g., 0.9) or pay a penalty. Some utility users might mistakenly think that they are not being penalized for low power factor because the utility contract contains no power factor clause. However, some utility companies base billing demand on kilovolt amperes rather than on kilowatts. For example, if the load of an activity were 4500 kW and the activity were operating at a 0.9 power factor, the accompanying demand would be 5000 kVA. For the same 4500 kW load and with the installation operating at 0.85 power factor, demand would be 5294 kVA. At a demand charge of $3 per kVA, the additional cost of the 0.85 power factor reflected in the demand charge for the month would be $882 (294 kVA x $3). The hidden cost of the low power factor could also be reflected in a higher energy charge, since a declining block rate energy charge structure is sometimes a function of kilowatt hour usage per kVA of billing demand (similar to the kWh per kW described previously). These factors may exist only for the purpose of creating a cost for low power factor in a rate structure that explicitly has no power factor penalty clause. Power factor penalties typically cost an installation from 1 to 3 percent of its total electrical utility bill.

Tables 2 and 3 show an analysis of electrical energy costs for an installation over a 2-year period; information for the tables was obtained from actual utility bills. As shown in Table 2, the energy, fuel adjustment, demand, and power factor penalty charges have been separated. This type of analysis shows the percentage of costs, both monthly and annually, for each billed item on the electrical utility bills. Information from this table will help determine what conservation efforts will achieve the most rapid payback (i.e., reduced consumption, demand limiting, power factor correction). Table

2 shows that in 1978, 64 percent of this installation's electric utility dollars were spent on energy costs, 11.7 percent on fuel adjustment charges, 23.6 percent on demand charges and 0.7 percent on power factor penalty charges. In addition, it shows that fuel adjustment charges fluctuate widely (5 to 18 percent) throughout the year and that power factor penalty charges increase during the air-conditioning season (June through September) because of additional inductive motor loads; thus, it indicates where power factor correction could be applied (i.e., air-conditioning equipment).

Table 3, which provides similar data for 1979, shows expenditures of 60 percent for energy, 17 percent for fuel adjustment, 22 percent for demand, and 0.8 percent for power factor penalty. Again, it is noted that the power factor penalty charges increase during air-conditioning months; in addition, the highest consumption (indicated by energy charges) occurs in December and January at the height of the heating season. Comparison of Tables 2 and 3 shows a substantial increase in costs for fuel adjustment charges, even though no changes in the utility contract rate occurred over the 2 years. This installation has an energy charge of $0.01404/kWh and a demand charge of $2.72/kW. The two tables show that the major areas of concern are reducing both energy use and demand. Power factor correction may not achieve early payback because of the costs of corrective equipment and annual power factor penalty expenditures. This type of analysis provides a starting point for determining where electrical energy costs can be reduced.

Building Electrical Consumption

The individual electricity-consuming components in a building consist of various combinations of lighting, heating, air conditioning, motors (fans and pumps), appliances, electronic equipment, vending machines, water coolers, exhaust fans, safety and security lighting, alarm systems, HVAC control, and clocks. To reduce building electrical consumption, it is necessary to know how much each component uses when it is operating and how long the component operates during a given period of time. Therefore, Chapter 4 briefly describes and provides power calculations for typical electrical systems.

The electrical power supplied to Army buildings is obtained from either single-phase or three-phase alternating current sources. Electrical energy is supplied to the buildings from transformers at various voltages (120, 208, 240, 277, or 480 V). Regardless of the magnitude of the voltage, the waveform is as shown in Figure 5. This cycle is completed 60 times per second (60-Hz frequency). A three-phase voltage source is composed of three single-phase sources of equal magnitude and 120 degrees out of phase with each other, as shown in Figure 6. Almost all electrical power systems serving Army buildings are three-phase, and when single-phase power is required, it is obtained from one phase of the three-phase system. There are two basic transformer connections to provide a three-phase source -- delta and wye. Figure 7 shows the transformer connection and typical voltages for these two methods, as well as a standard single-phase connection.

The power consumed by a "single-phase" electrical component is determined from the product of the line voltage (as measured with a voltmeter), the line current (as measured with an ammeter), and a factor called power factor. For a purely resistive load, such as an electric heater or an incandescent lamp,

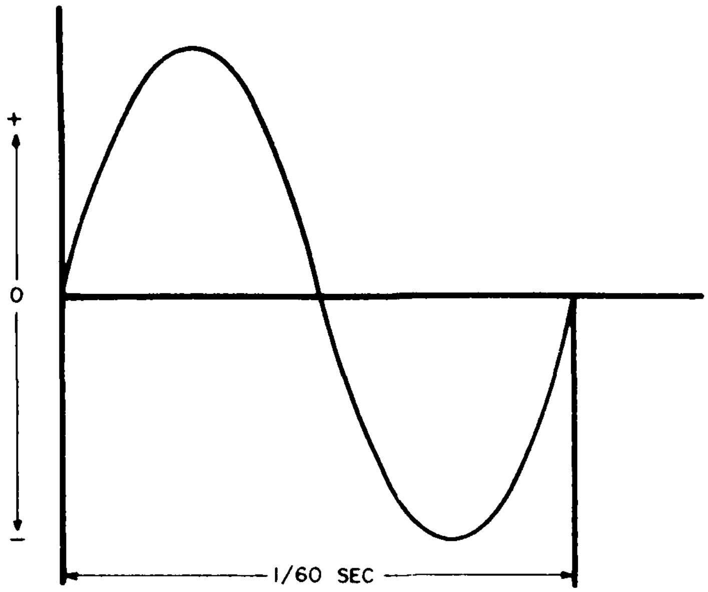


Figure 5. Single-phase voltage waveform (60 Hz).

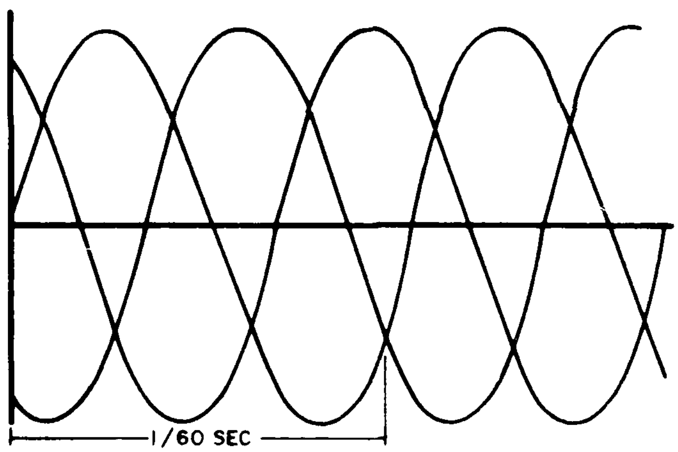
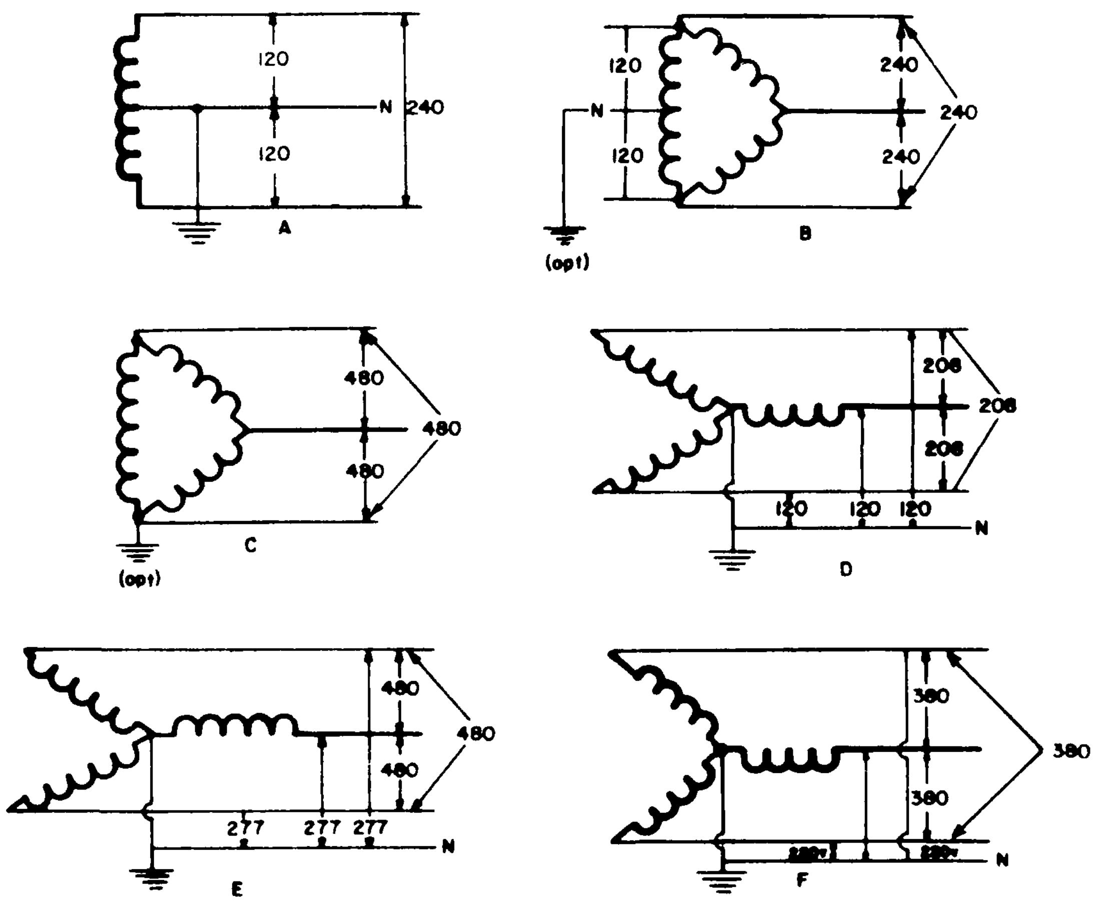


Figure 6. Three-phase voltage waveform (60 Hz).

the power factor is unity and the product of voltage and current (volts times amps) give the power being consumed by the device (watts). However, with other building loads, such as motors and discharge-type lighting, the power factor is less than unity and enters the calculation. The power factor, which is the cosine of the phase angle difference between the voltage and current waveforms represents the magnetizing current required to operate an inductive electrical device (see the Power Factor section of Chapter 5). Typically, the power factor of a purely resistive load is 1.0, for discharge-type lights, 0.92 to 0.98, and for induction motors, from 0.6 to 0.95. (Power factors lower than 0.6 are also possible, especially for operating unloaded motors.) Therefore, if a 3-hp, single-phase motor measured at 240 and drawing 16 amperes had a power factor of 0.85, its hourly energy consumption would be 3264 watts (240 V x 16 x 0.85). The volt-amperes required would be 3840.

"Three-phase" power is calculated similarly, except another constant in the formula is reqired -- 1.732, which is the square root of 3. For example, a 5-hp three-phase motor measured at 208 V and 16 amperes and having a power factor of 0.85 would have an energy consumption of 4900 watts (208 x 16 x 0.85 x 1.732). The energy consumed by an electrical component can be calculated by knowing the number of hours the component operates (i.e., if the 5-hp motor mentioned above were operated for 10 hours, its power consumption would be 49,000 watt hours, or 49 kWh). Individual components that consume electrical energy in a building are discussed separately in Chapter 4.



A -- single-phase, 3-wire 120/240 V
B -- 240 V delta with 120 V tap
C -- 480 V delta with no tap
D -- 120/208 V wye
E -- 277/480 V wye
F -- 220/380 V wye

Figure 7. Typical voltages for transformer connections.

4 BUILDING COMPONENTS CONSUMING ELECTRICAL ENERGY

Lighting

Lighting is a major use of electrical energy in buildings (10 to 30 percent or more). The goal of lighting energy conservation is to provide an adequate quantity and quality of light for specified tasks using a minimum of energy. Six lighting problems can contribute to electrical energy waste.

1. Lighting levels may be too high for the working environment.

2. The building's lighting system may be inefficient.

3. Lights may be left on when the space is not being used.

4. Controls are inadequate.

5. Work stations are improperly located to take maximum advantage of the lighting system or building design.

6. Existing systems may be maintained poorly.

The FE should know the most commonly used lighting types before taking action to reduce lighting energy use. Technical Note No. 80-17 is an excellent source of lighting type description.[9] Six basic types of lighting can be used: incandescent, fluorescent, mercury vapor, metal halide, high-pressure sodium, and low-pressure sodium (low pressure sodium only used in accordance with AR 420-43). The latter four types are known as high-intensity discharge (HID). Table 4 gives the characteristics of each type of lighting.

Incandescent lamps are widely used; however, other light sources, particularly fluorescent, have been displacing incandescent lamps for many interior applications. Although incandescents are the most commonly used, they are the least efficient of the light sources (i.e., they have the lowest light output per watt input); the average output of incandescent lamps is 16 to 18 lumens/watt. The simplicity of application and the low prices of the lamp and the fixture are the main reasons for the general use of incandescent lighting. Its efficacy increases as lamp wattage increases. This makes it possible to save both energy and fixture costs when one higher wattage lamp is used instead of two lower wattage lamps. Incandescent lamps are available in smaller sizes than other types of lighting and can be used when only low-level lighting or indicator lamps are required. Incandescents can also be readily and economically dimmed for decorative effects or to save energy.

The fluorescent lamp, the second most commonly used light source, is used in almost all Army buildings, including housing, administration, storage, and industrial plants. Unlike the incandescent lamp, the fluorescent lamp requires a ballast to initially strike the electric arc in the tube and to maintain the proper voltage and current. Lamp sizes range from 4 to 250

[9] Energy Conservation and Proper Lighting, Technical Note 80-17 (Office of the Chief of Engineers, 18 September 1980).

Table 4

Characteristics of Lighting System Types

Type of Lamp	Average Lumens per Watt: Initial (Lamp Only)	Average Lumens per Watt: Mean (Including Ballast)	Average Life (Hours)	Warmup (Restrike), in Minutes
Incandescent	15-24	13-23	750-2500	Immediate
Mercury Vapor	40-60	23-46	18-24,000	5-7(3-6)
Fluorescent	63-100	44-75	12-24,000	Immediate
Metal Halide	80-115	56-83	7.5-20,000	2-5(10-20)
High-Pressure* Sodium	65-140	41-111	24,000	3-4(0.5-1)
Low-Pressure Sodium (see AR 420-43)	132-183	70-143	18,000	7(0-1)

*For lamps designed for HPS ballasts. Figures are lower for lamps designed for mercury vapor ballasts.

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watts. The efficacy of the lamp increased with lamp length (i.e., 8-ft [2.4-m] tubes are more efficient that 4-ft [1.2-m] tubes). The efficacy of a fluorescent lamp and ballast combination ranges from 44 to 75 lumens per watt, with an average of about 60 lumens/watt. The reduced wattage fluorescent lamps introduced recently use from 10 to 20 percent less energy than conventional fluorescent lamps. Fluorescent lamp life is rated according to the number of operating hours per start, e.g., 20,000 hours at 3 hours of operation per start. The greater the number of hours operated per start, the greater the lamp life is. Because fluorescent lamp life ratings have increased, the number of times a lamp is turned on or off has become less important. Generally, when spaces are unoccupied for more than a few minutes, the lamps should be shut off. Actually fluorescent and incandescent can be treated alike in the matter (for HID lamps the restrike time must be considered).

The four other types of lamps are categorized as HID lamps. Each requires 1 to 7 minutes to start up and achieve full brightness, and most require a restrike time if the lamp is shut off. (A new device on the market allows for instant restrike for high pressure sodium lamps.)

Mercury vapor lamps produce light when the electrical current passes through a small amount of mercury vapor. The lamp consists of two glass envelopes: an inner envelope in which the arc is struck, and an outer protective glass bulb. The mercury vapor lamp requires a ballast and fixture designed for its specific use. Lamp sizes range from 40 to 1000 watts and normally have an efficacy of [illegible] to 65 lumens per watt.

Metal halide lamps are very similar to mercury vapor lamps; however, their efficiency is one and one-half to two times greater -- 90 to 120 lumens per watt. Again, specifically designed ballast and fixtures must be used. Metal halide lighting produces better color rendition than mercury vapor lamps. Because of their relatively short life (10,000 to 15,000 hours) their use is generally restricted to applications where color rendition is important and their higher efficiency will offset replacement costs. Lamp sizes range from 175 to 1500 watts.

High-pressure sodium lamps have the highest efficiency of all lighting normally used indoors. The lamps range in size from 50 to 1000 watts and require a specifically designed ballast. The high-pressure sodium lamp produces light when electricity passes through the pressurized sodium; the light produced is not the characteristic bright yellow associated with sodium, but rather a golden white light. Although high-pressure sodium lamps were first used for street and outdoor lighting, they are now also used in industrial plants and in many commercial and institutional office and school applications. High-pressure sodium lamps normally provide an efficiency of 1[illegible] to 140 lumens per watt.

Low-pressure sodium (LPS) lamps are the most efficient of all commonly used lamps, providing up to 180 lumens per watt, however, their use is limited by AR 420-43. Indoor use is restricted because of their monochromatic light output, in which colors all appear as tones of gray. These lamps range in size from 35 to 180 watts. Their primary uses are for street and highway lighting and for outdoor and security lighting. Indoor applications for areas such as warehouses are practical if color distinction is not important, i.e., colors of objects have little effect in identifying (or camouflaging) them. Object shapes are sharply outlined, even at normal, low foot-candle levels. Therefore, low-pressure sodium is normally suitable for security lighting.

In addition to security lighting, low-pressure sodium is suitable for street lighting, but its use for parking lots is questionable. On the highway, colors of cars are of minor, if any, importance, but the colors of cars parked in a lot are important to motorists trying to locate them. Indoors, low-pressure sodium lighting can be used in cold storage rooms. Its starting characteristics allow easy cold ambient temperature starting, and the low energy required means reduced loading on cooling equipment. (This is not a good application, however, if items in cold storage are identified by color-coded labels.) Another application of low-pressure sodium is for night lighting of stores and other facilities where interior spaces are visible from the street. Low pressure sodium lighting can only be used in accordance with AR 420-43.

The Federal government has mandated that general lighting levels in buildings be established at 50 foot-candles at the working surface of an occupied work station, 30 foot-candles at the floor of work areas, and fewer than 10 foot-candles in nonworking areas such as corridors and hallways. Note that this criterion is overidden for some applications (see DOD 4270.1M and TN [illegible]-17). This 50/30/10 foot-candle requirement may be difficult to maintain in many Army buildings because the interior lighting design may provide only uniform illumination levels which have little relationship to the lighting requirements of a specific task. The designer cannot always define the exact nature or location of the specific task area or area use. This is compounded by additions, partitions, furniture, wall, ceiling, and floor finish, all of which affect the lighting system's effectiveness. To determine if the 50/30/10 foot-candle requirement has been achieved, a building's lighting must be measured with a foot-candle meter. (Note that 50/30/10 is not essential but only a guide since lamp age, maintenance, and other factors can influence the overall light output. The requirement is for the general lighting over a period of time. Task lighting can be greater than the 50 foot-candle limit.)

There are usually ways to change a lighting system's efficiency. If the wiring and lighting systems are flexible enough to allow luminaire relocation, ease of adding switching, or individual control, it may be possible to modify lighting levels in specific work areas. Where this flexibility does not exist, it may be necessary to remove or add luminaires or even remodel the entire lighting system to obtain proper illumination and still reduce energy consumption. In some cases, it may be sufficient to replace lamps with lower-wattage lamps, remove lamps from some fixtures, or use "dummy" tubes in fluorescent fixtures.

A lighting system is interrelated to other systems such as heating and cooling. Heating and cooling systems can be strongly influenced by eliminating luminaires or changing systems, so it becomes important to consider heating and cooling functions during the lighting analysis. It must be recognized that reduced lighting can increase the heating load and reduce the cooling load in a building.

While conservation is important, it must be achieved while maintaining consistent standards of visual comfort, aesthetics, and productivity. One area of energy waste is when lighting levels exceed the amount required for the tasks. All working areas should be measured with a foot-candle meter, and if changes are necessary, an intelligent approach must be used. Be careful not to overdo lighting reduction. Maintained illumination, not initial, should be at the recommended level. If measurements are made of a new system in a freshly painted room, the foot-candle level could easily be twice the calculated level -- luminaires are new and clean, lamps are operating at their initial rather than mean lumen output, and walls, ceilings, and floors are at maximum reflectivity. As time goes on, all these factors will age, and the lighting level may decrease to the recommended level or even below it. All methods of calculating lighting levels take these factors into account, and if the design was properly done, the actual maintained level should be very close to the design objective.

A common approach to lighting energy reduction is removing one or more lamps from fluorescent luminaires. This approach has several shortcomings. If one lamp is removed from a two-lamp luminaire, the remaining lamp will be extinguished since the two are usually series-connected to the same ballast. The result of delamping two-tube luminaires may be uneven or spotty lighting, and if too many are disconnected, the light level in the room may drop below recommended levels. An additional problem occurs if the ballast is left energized; it will continue to consume power (6 to 10 watts) even though no light is being emitted from the luminaire. In addition, the power factor of the ballast, normally at about 0.90 when tubes are connected, drops to 0.10 to 0.20. Delamped luminaires with energized ballasts will decrease the overall building power factor, and may result in a higher power factor penalty charge. An example of how power factor is affected is shown below.

Example: Effect of Delamping Fluorescent Luminaire and Leaving Ballasts Connected on System Power Factor (20 Luminaires)

Assumptions:

System 1.	Two standard lamps and standard ballast	94 watts @ 92% pf.
	Ballasts without lamp	10 watts @ 15% pf.
System 2.	Two high-efficiency lamps and standard ballast	73 watts @ 92% pf.
System 3.	Two high-efficiency lamps and high efficiency ballasts	70 watts @ 92% pf.
	High-efficiency ballast without lamp	6 watts @ 15% pf.

System	Situation	Calculations	Watts	Volt-Amps	pf
1	All luminaires lamped	20 x 94	1880	2044	92%
	10 delamped	(10 x 94)+(10 x 10)	1040	1689	62%
2	All luminaires lamped	20 x 73	1460	1587	92%
	10 delamped	(10 x 73)+(10 x 10)	830	1460	57%
3	All luminaires lamped	20 x 70	1400	1522	92%
	10 delamped	(10 x 70)+(10 x 10)	760	1161	65%

Note: Effect on power factor of the entire electrical system may or may not be significant, depending on relative sizes of the various building loads (i.e., lights, motors, appliances). Example courtesy of Mr. Jack Ronan, DAEN-MPO-U.

These problems can be partially resolved by the use of "dummy" tubes in a two-lamp fluorescent luminaire. Two types of these devices reduce light output from the luminaire by 50 or 70 percent respectively, with a corresponding energy savings. These capacitive tubes have the same configuration and dimensions as a fluorescent lamp and are used to replace the lamp removed from the two-lamp pair. The remaining lamp stays lit at reduced power; since the tube is transparent, light from the remaining lamp can cross through the capacitive tube, preserving relatively good light uniformity across the area. The power factor is also preserved within this lamp, and since the current through the ballast is reduced, ballast heat is also reduced. This tube permits modification of lighting without spotty effects produced by simply removing lamps or disconnecting luminaires. Spotty or uneven lighting is not as noticeable if two lamps are removed from a four-tube luminaire, since the general lighting pattern remains roughly equivalent. These luminaires have two ballasts, with one operating each set of two lamps. Again, however, the unused ballast in the four-tube luminaire must be disconnected to achieve the greater energy savings and eliminate greater inductive loads on the building.

A recently introduced, high-output fluorescent lamp, sold under various trade names, would be useful in most installations. This type of lamp saves from 15 to 25 percent of the energy used for lighting but without noticeably decreasing light output. The level of illumination should be checked after lamps are removed and changed. It may even be necessary to replace some of the remaining lamps with similar lamps having a higher output. This technique will detract little from the total energy savings, and will help insure that the system continues to provide adequate light.

Efficacy varies among lamps consuming the same number of watts; even lamps of the same type, but of different colors, shapes, gaseous fields, and internal coatings show variations. The efficacy of lamps is measured in lumens (usable light) produced per watt of input. Selecting more efficient lighting will allow the removal of some lamps, as long as the working surface retains the required number of foot-candles. More efficient lamps also impose smaller heat loads on air-conditioning systems. In winter, any heat loss caused by reducing wattage can generally be supplied more efficiently by the heating system.

Substantial lighting energy savings can be achieved by replacing inefficient lighting systems. The new lamps should be the most efficient practicable and should be compatible with the application. Consider replacing existing lamps with a lower-wattage type which provides the same or a lower level of illumination. This method is particularly applicable where current lighting levels are higher than recommended or where occupant density makes uniform lighting the most practical approach. Be certain that new lamps are compatible for use with existing ballasts in either fluorescent or high-intensity discharge luminaires. Table 4 (p 24) ranks the efficacy of various types of lamps. Selection of the most efficient lamp must be evaluated on the basis of a specific application and the performance characteristics of the individual lamps being considered. Changing from incandescent to a more efficient light source can give paybacks in as little as a few months or 2 years, depending on how much the installation's electrical energy costs.

Waste occurs when lights are left on but are not used. When lights are left on in areas which are unoccupied or unused for any period of time (e.g., outdoor parking lots, exterior lighting, interior lighting, closets, etc.), the amount of energy wasted often approaches or exceeds the amount used by other systems during the week. In fact, the cost of this waste for only 1 year may equal the initial cost of installing controls to eliminate it. In addition, lights that are inadvertently left on are highly visible to the public and can have detrimental effects on an otherwise good energy conservation program. Generally, lights should always be turned off when they are not required.

In many cases, modifying existing lighting controls and adding new ones can greatly affect energy consumption. When natural light is available, consider using photocell switching to turn off banks of lighting in areas where natural light is sufficient for the task. For outdoor lighting, photocells or time clock controls should be used whenever feasible. Parking areas, building exteriors, and identification signs usually require lighting during only a part of the evening. Such lighting, except for security and safety lighting, can be turned on by photocells when light is needed and off by time switches when expected use is over. Controls that automatically turn lights off after they have been activated for a particular period of time should be used in areas of buildings that are either infrequently used or used only for brief periods. A good example of efficient use of timer switches is for control of bin lights in storage areas; lights can be turned on as needed, and will switch off automatically in 15 to 30 minutes. In multipurpose areas, dimmer controls can be used if different amounts of illumination are required for different activities. Selective switching of large banks of lights may also be possible, but must be carefully considered from an economic standpoint. Localized switches should be provided near doorways so that it may be possible to light only portions of large generally lit areas. When properly used, localized switching will usually save enough energy to provide payback on the investment within a short period of time. Consideration should also be given to individually switched lamps, so that the building occupants can use individual lamps as needed.

In many Army buildings, work stations can be relocated to take maximum advantage of the lighting system. First, the general lighting pattern of the room should be surveyed; then desks and other work surfaces should be moved to a position that will use the existing light system to its greatest advantage. It may be possible to group tasks which require about the same level of illumination; this may provide an opportunity to reduce the amount of light in areas where higher illumination is unnecessary. Work requiring the highest illumination levels should be located next to windows so as to achieve best use of natural lighting.

Maintenance of the lighting system's components can greatly affect lighting quality, quantity, and energy waste. As any lamp ages, its light output decreases; however it still consumes the same amount of energy. When dust and dirt accumulate on lamps and luminaire surfaces, the amount of light emitted from the luminaire is reduced. The amount and rate of light loss varies with the environment, type and amount of ventilation, type of luminaire, and the age of the luminaire; for example, light loss resulting from dirt accumulation in a maintenance building would be greater than in an administration building. Up to 50 percent of a lamp's initial light output can be lost if there is no cleaning program and lamps are burned to their expiration and replaced one at a time.

Common practice indicates that when the light output of a group of lamps has fallen to 70 percent of their original output, the entire group should be relamped at the same time. This is also a good time to determine if a more efficient or lower-wattage lamp would be suitable. Lamps and the luminaires, including diffusers, should be cleaned regularly to ensure maximum efficiency. Lenses or shields that have become yellowed or hazy should be replaced. In addition, the ceilings, walls and floors should be cleaned or repainted in light colors to improve reflective qualities. When daylight is used, windows should also be washed regularly. The design of the lighting system must conform to the recommended standards for quality of illumination, light distribution, shadows, source brightness, and visual comfort, as outlined by the Illuminating Engineering Society, and consistent with the energy consumption lighting levels mandated by the Federal government (50/30/10 foot-candles).

Table 5 shows some common lamp types, what can be used to replace them, and the estimated savings achieved by the modification.

Motors

It is estimated that 60 percent of all electricity generated in the United States is used to power motors. Despite the large number of fractional horsepower motors, integral horsepower motors consume an estimated 90 percent of the electrical energy required by motors.[10] After electrical lighting, electrical motors are the item of electrical equipment most commonly found on Army installations. Pumps, air conditioning units, fan coils, ventilation systems, and simulators all use electrical motors.

Figure 8 shows typical efficiency and power factor as a function of motor loading conditions. Unit efficiency drops rapidly when a motor is loaded to less than 40 percent of its rated full load, and power factor degrades immediately upon application of the motor at less than full load. Figure 9 shows a typical relationship of motor loading to current and energy use. At 20 percent load, the current shown is still 40 percent.

Four factors should be considered when evaluating a motor's efficiency: efficiency rating, power factor, motor load variation, and voltage tabulate variation.

The efficiency rating shows how well the motor converts electrical energy into mechanical energy. The larger the rating, the more efficiently the motor uses energy, since electrical power rate charges are based on total power use and peak demand requirements over a given time. It is usually important to use motors with the highest efficiency level available, since use and demand charges are then minimized. The application of high efficiency motors requires some thought to insure that proper frame size is obtained, and to determine whether payback is achieved by considering the running hours, energy costs, and cost differential between conventional and high efficiency motors of equal output. A single formula can be used to make this comparison:

$$S = HP \times 0.746 \text{ kWh/hp} \times C \times N \left(\frac{1}{E_a} - \frac{1}{E_b}\right) \qquad \text{[Eq 1]}$$

where:
- S = annual savings, in dollars
- HP = actual load
- C = energy cost, \$/kWh
- N = running hours per year
- $E_{a,b}$ = respective motor efficiencies.

[10]Energy Technical Center Hospitality, Lodging, and Travel Resource Foundation, Inc., "High Efficiency Motors: Are They Cost-Effective?" Specifying Engineer (August 1980).

Table 5

Common Lamp Types

WHERE YOU NOW USE	CHANGE TO THIS	GET THIS MUCH LIGHT	SAVE THIS MANY WATTS PER LAMP	KILOWATT-HOURS SAVED OVER LIFE OF LAMP
F40	F40 REDUCED WATTAGE	SAME OR MORE	7	140
F96	F96 REDUCED WATTAGE	SAME OR MORE	17.5	315
F96 HO	F96HO REDUCED WATTAGE	SAME OR MORE	17.5	315
F96 1500 MA	NEW F96 PG REDUCED WATTAGE	SAME OR MORE	41	815
100 WATT	50R20 *	SAME OR MORE	50	100
150 WATT FLOOD	75ER30 *	SAME OR MORE	75	150
200 WATT	120ER40 *	SAME OR MORE	80	160
150 WATT FLOOD	120ER40 *	UP TO 100 PERCENT MORE	30	60
300 WATT FLOOD	120ER40 *	SAME OR MORE	180	360
175 WATT MERCURY	150 RETROFIT TYPE HPS **	UP TO 120 PERCENT MORE	25	300
250 WATT MERCURY	215 RETROFIT TYPE HPS **	UP TO 130 PERCENT MORE	35	420
400 WATT MERCURY	400 RETROFIT TYPE METAL HALIDE	UP TO 300 PERCENT MORE	—	—
1000 WATT MERCURY	1000 RETROFIT TYPE METAL HALIDE	UP TO 440 PERCENT MORE	85	850

* Down light applications.
**Stop gap measure -- more efficient results obtained by using high pressure suction (HPS) lamps with HPS designed ballasts.

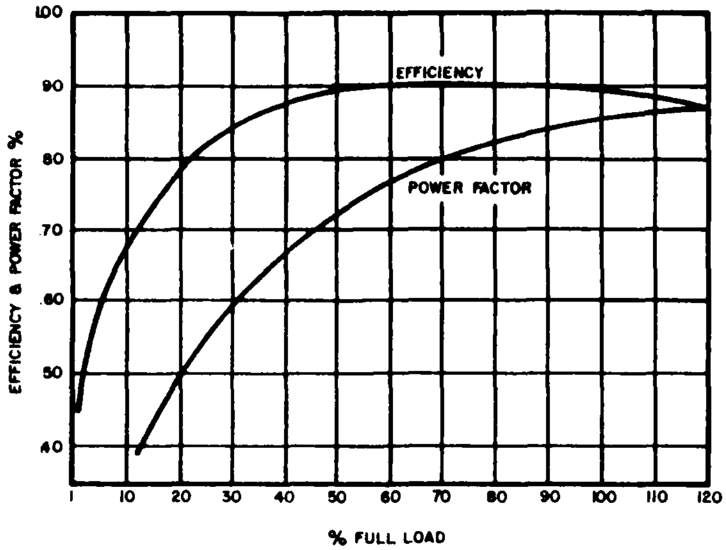

Figure 8. Efficiency and power of typical three-phase motor.

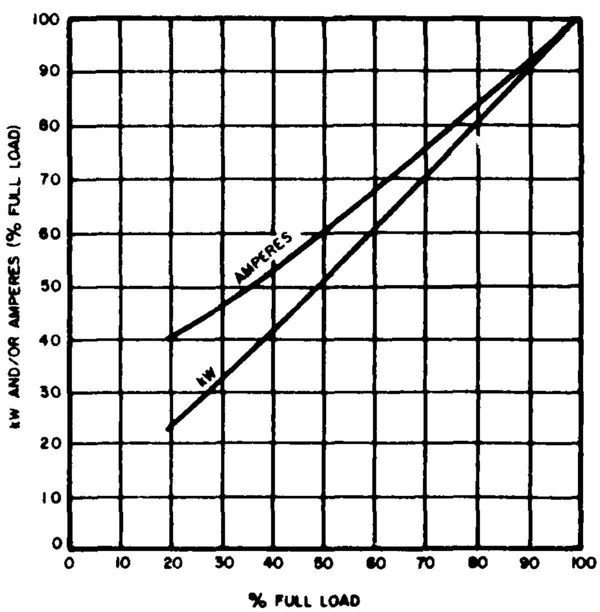

Figure 9. Typical motor current and energy versus percent full load.

Motor line current consists of real and reactive components. The real current produces power and does the work. The reactive current provides the magnetizing energy for the motor. The magnitudes of these current components determine the motor power factor. For a given efficiency, a higher power factor means that the motor requires less total current. Lower line current means that less energy is wasted in the feeder circuits serving the motor. Variation of motor load above 50 percent full load affects efficiency only slightly, but can greatly affect the power factor. Efficiency is relatively stable from 50 to 125 percent of a motor's full load, but the power factor drops off severely as the motor is underloaded.

Larger motors than are necessary are often specified to provide safety margins. However, most motors have a 15 percent reserve service factor over their full load rating. The problem of oversizing is not as simple as this, however; other major contributors to oversizing are the competitive bidding concept, contractor approval of his own shop drawings, inefficient inspection forces, nominal equipment sizes available, and design error. Motors that have burned out are often replaced with larger sizes to prevent future problems. Such overspecification has become common practice, but is unnecessary and costly in terms of wasted energy. If motors are not specified close to their rated load, energy is not being used efficiently, regardless of the motor's efficiency and power factor rating. The power factor is more sensitive than the efficiency rating to line voltage variation, so voltage variations should be considered when selecting new or replacement motors. With a 10 percent variation from rated voltage, efficiency typically varies only 1 percent at the rated horsepower; however, the power factor can vary as much as 15 percent in the opposite direction for the same voltage variations.

Other Components

Numerous other building components consume electrical power: food preparation appliances, domestic water coolers, vending machines (especially hot- or cold-served food), refrigerators, freezers, coffee pots, typewriters, photocopiers, safety and security lighting systems, security alarm systems, and clocks. Although some of these items appear trivial, many are continuous electrical energy consumers. Tables 6 through 14 and Figures 10 through 15 show analyses of electrical energy consumption for both summer and winter for three different Army buildings -- a volar barracks, a dental clinic, and an administration building.

Table 6 shows that the lighting consumption is roughly 25 percent of the total daily consumption in the volar barracks. Pumps and fans constitute about 55 percent of the total electrical consumption, whereas appliances, laundry, and miscellaneous make up the remaining 20 percent. The monthly consumption given in Table 7 shows that summer electrical consumption in this building is less than the winter consumption. This can be attributed to: (1) a decreased energy use for lighting during the summer because of longer daylight hours, (2) soldiers being in barracks more in cold weather, and (3) the barracks' location in a predominately heating climate; therefore, less energy is required for the fan coil units during the cooling season.

The daily consumption given in Table 8 shows that Saturdays and Sundays are slightly higher electric energy use days than workdays; more personnel are

Table 6

Connected kW and Percent Consumption -- Barracks

Equipment	Connected kW	% of Daily Consumption S	W
Lights	13.8	26	25
Pumps	4.6	29	25
Fans	11.3	24	32
Appliances	14.0	11	9
Laundry	15.1	8	7
Miscellaneous	0.4	2	2

Table 7

Monthly Consumption, 1978 -- Barracks

Mon	kWh	Mon	kWh
Jan	13,941	Jul	9,597
Feb	11,881	Aug	10,577
Mar	13,995	Sep	9,466
Apr	11,126	Oct	11,756
May	10,745	Nov	11,734
Jun	10,358	Dec	12,611

Table 8

Daily Consumption, Maximums/Minimums -- Barracks

	Summer			Winter		
Day of Week	Daily (kWh)	Hourly MIN (kWh)	Hourly MAX (kWh)	Daily (kWh)	Hourly MIN (kWh)	Hourly MAX (kWh)
Sat	361	12	19	423	14	25
Sun	398	12	21	463	14	25
Tues	356	12	23	397	14	23
Wed	381	12	22	421	13	27

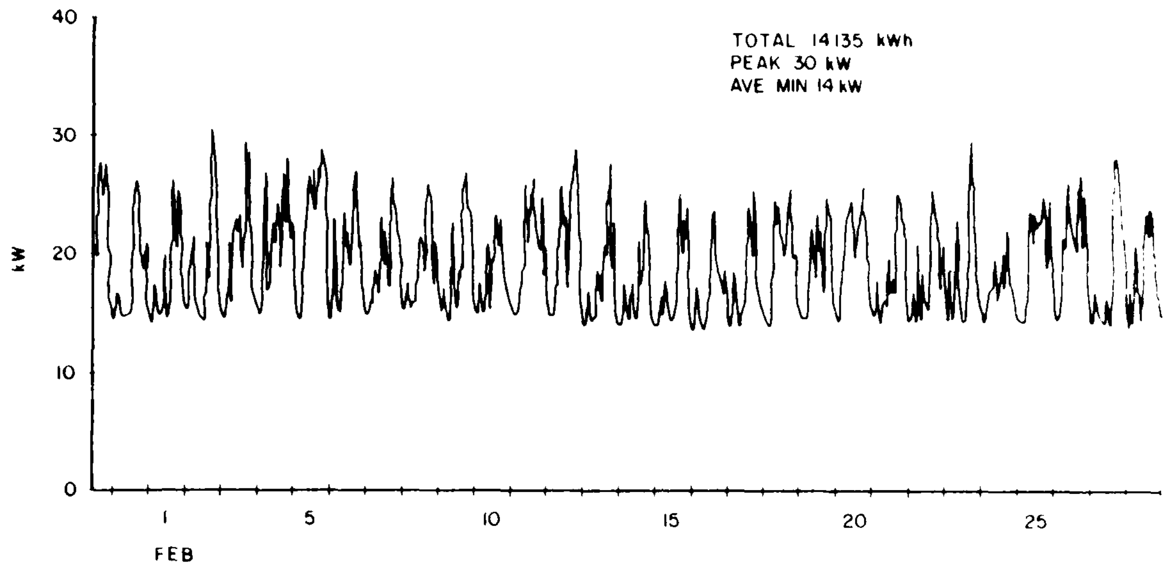

Figure 10. Electrical consumption profile, barracks -- winter.

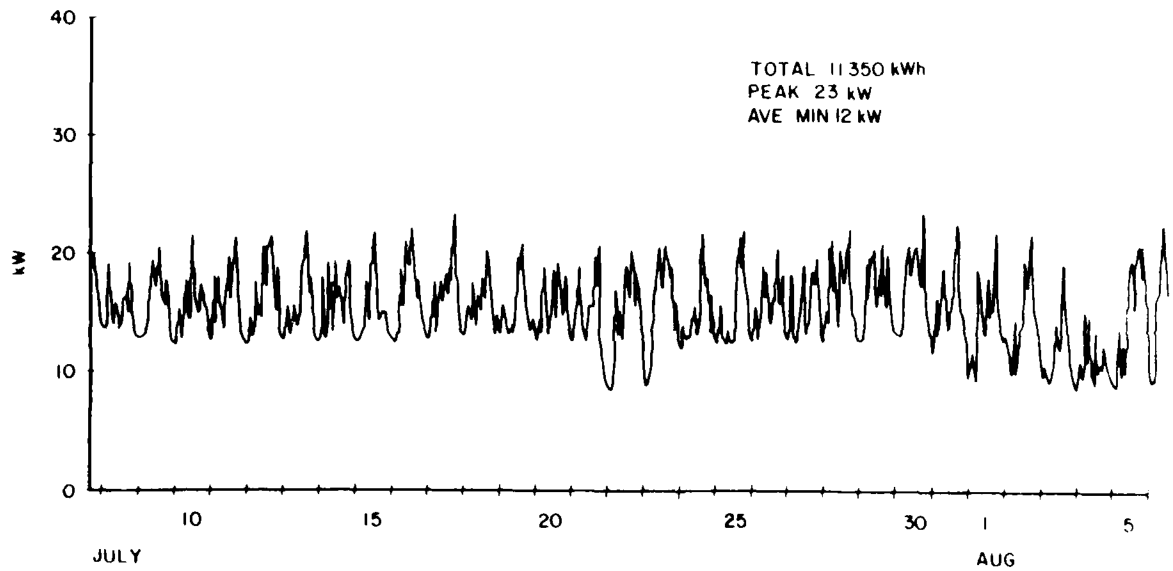

Figure 11. Electrical consumption profile, barracks -- summer.

in the barracks on the weekend. Figures 10 and 11, which show profiles of the barracks energy use, indicate that during the winter months the 14-kW minimum demand, extended over a 24-hour period, accounts for more than 70 percent of daily total electrical use. Comparisons of Figures 10 and 11 also show that the average minimum demand is not significantly changed from summer to winter; however, the peak demand increases in the winter months to 30 kW versus 23 kW in the summer months.

Tables 9, 10, and 11 show similar information for a dental clinic. Lighting consumption during the summer amounts to only 7 percent of the total daily consumption, whereas air-conditioning consumption accounts for 52 percent (see Table 9). The combined consumption for all air-conditioning functions, including fans and pumps, amounts to 68 percent of the total daily consumption during the summer. Other major electricity-consuming components in the dental clinic are the dental equipment, such as the air supply equipment, dental ovens, high-intensity lighting, and sterilization. Significant contrasts can be seen in Table 9 for winter consumption, where lights now account for 16 percent of the daily consumption. Heating fans and pumps amount to 36 percent, and building dental functional requirements amount to 46 percent of the winter daily consumption. Table 11 indicates that daily winter consumption is considerably less than daily summer consumption because of high air-conditioning requirements. Large differences between summer and winter monthly use are also evident, as shown in Table 9. Figures 12 and 13 show the hourly profiles for a winter and summer month.

Tables 12, 13, and 14 show that in the administration building, lighting accounts for 26 to 28 percent of total daily consumption, and pumps and fans for 57 percent, and daily appliance use for 10 percent. The monthly figures shown in Table 13 indicate that winter consumption is higher than summer consumption, again because of a higher lighting load (shorter daylight hours). This is substantiated by comparing Figures 14 and 15. The building exhibits a high baseline load (13 kW) which constitutes more than 54 percent of the building's energy consumption. This energy is being consumed even when the building is not occupied or used for its administrative function.

It is important to reiterate that HVAC, motors, pumps, and fans often account for 50 to 70 percent of a building's total electrical consumption; therefore, this is an important area for possible electrical energy reduction. The buildings that are not occupied at night or on weekends should be equipped with time switches to allow shut off of electrical equipment when the building is unoccupied. The switches can be interlocked to a low-set (40°) thermostat to allow for override and prevent possible freezing.

Electrical energy consumption in military family housing is extremely variable, as shown in Figure 16. The figure shows specific results of a metering test performed on military family housing from January to August 1979.[11] The figure shows the mean electrical consumption, range of consumption of the high and low consumer, and one standard deviation from the mean developed from a sample of 86 identical family housing units. Sixty-eight percent of the units fall between the standard deviation marks on the figure. The range of usage in identical units (250 to 1400 kWh per month in March)

[11] DOD Family Housing Military Test, Report to the Congress (Office of the Deputy Assistant Secretary of Defense [Installation and Housing], 1 March 1980).

Table 9

Connected kW and Percent Consumption -- Dental Clinic

Equipment	Connected kW	% of Daily Consumption S	% of Daily Consumption W
Lights	7.1	7	16
Air Cond	32	52	
Fans	12.3	15	28
Pumps	3.6	1	8
Air Supply	24	5	10
Dental Equipment	80	19	36
Miscellaneous	13	1	2

Table 10

Monthly Consumption, 1978 -- Dental Clinic

Mon	kWh	Mon	kWH
Jan	13,540	Jul	26,080
Feb	12,660	Aug	29,470
Mar	13,910	Sep	28,660
Apr	11,930	Oct	13,500
May	18,970	Nov	14,220
Jun	21,760	Dec	14,210

Table 11

Daily Consumption, Maximums/Minimums -- Dental Clinic

Day of Week	Summer Daily (kWh)	Summer Hourly MIN (kWh)	Summer Hourly MAX (kWh)	Winter Daily (kWh)	Winter Hourly MIN (kWh)	Winter Hourly MAX (kWh)
Sat	670	23	34	207	8	9
Sun	760	23	40	207	8	9
Tues	933	24	65	506	8	43
Wed	1009	24	65	501	8	42

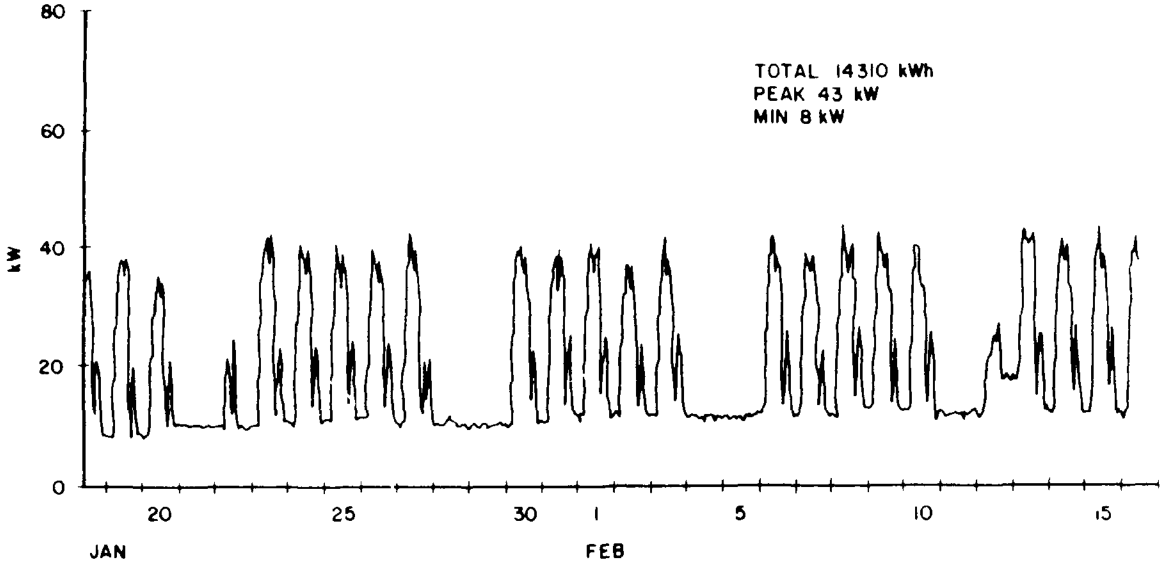

Figure 12. Electrical consumption profile, dental clinic -- winter.

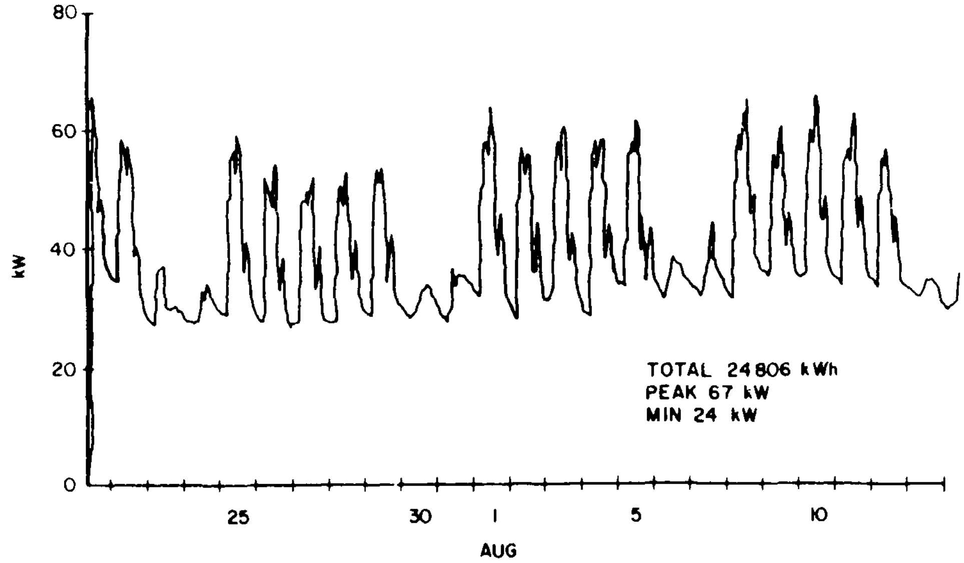

Figure 13. Electrical consumption profile, dental clinic -- summer.

Table 12

Connected kW and Percent Consumption -- Administration

Equipment	Connected kW	% of Daily Consumption	
		S	W
Lights	40.0	25	28
Pumps	3.5	7	6
Fans	20.5	51	51
Appliances	9.0	11	9
Water Heating	5.0	3	3
Miscellaneous	10.0	3	3

Table 13

Monthly Consumption, 1978 -- Administration

Mon	kWh	Mon	kWh
Jan	19,750	Jul	18,950
Feb	16,710	Aug	19,490
Mar	17,020	Sep	16,080
Apr	18,480	Oct	17,650
May	19,070	Nov	17,290
Jun	18,150	Dec	17,360

Table 14

Daily Consumption, Maximums/Minimums -- Administration

	Summer			Winter		
Day of Week	Daily (kWh)	Hourly MIN (kWh)	Hourly MAX (kWh)	Daily (kWh)	Hourly MIN (kWh)	Hourly MAX (kWh)
Sat	468	14	24	475	18	22
Sun	454	14	22	488	18	23
Tues	652	15	40	744	20	42
Wed	663	17	43	688	16	42

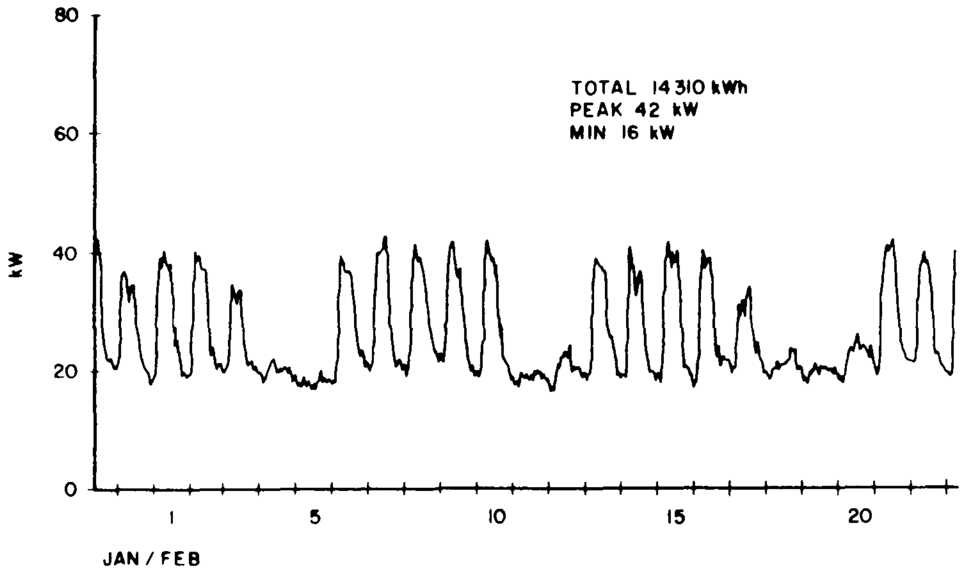

Figure 14. Electrical consumption profile, administration building -- winter.

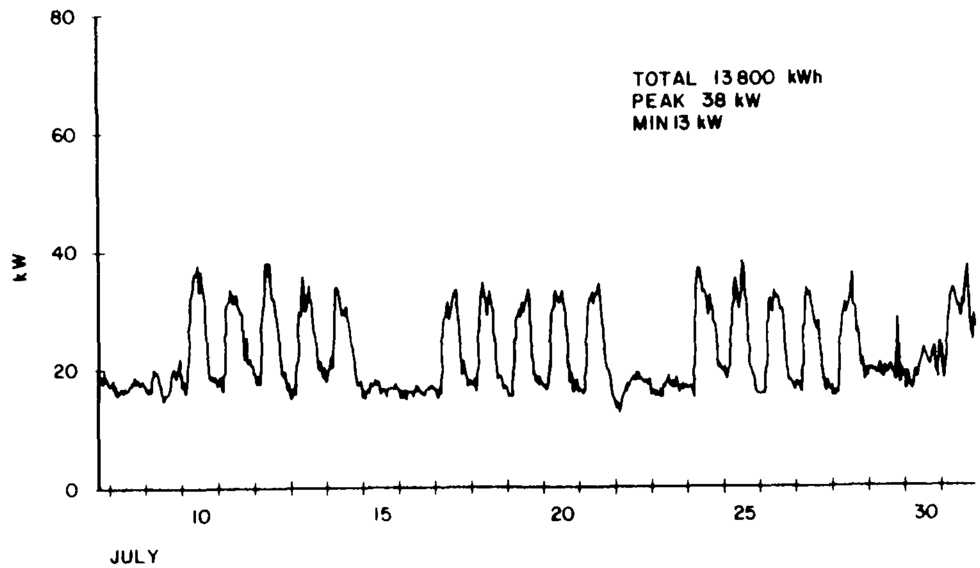

Figure 15. Electrical consumption profile, administration building -- summer.

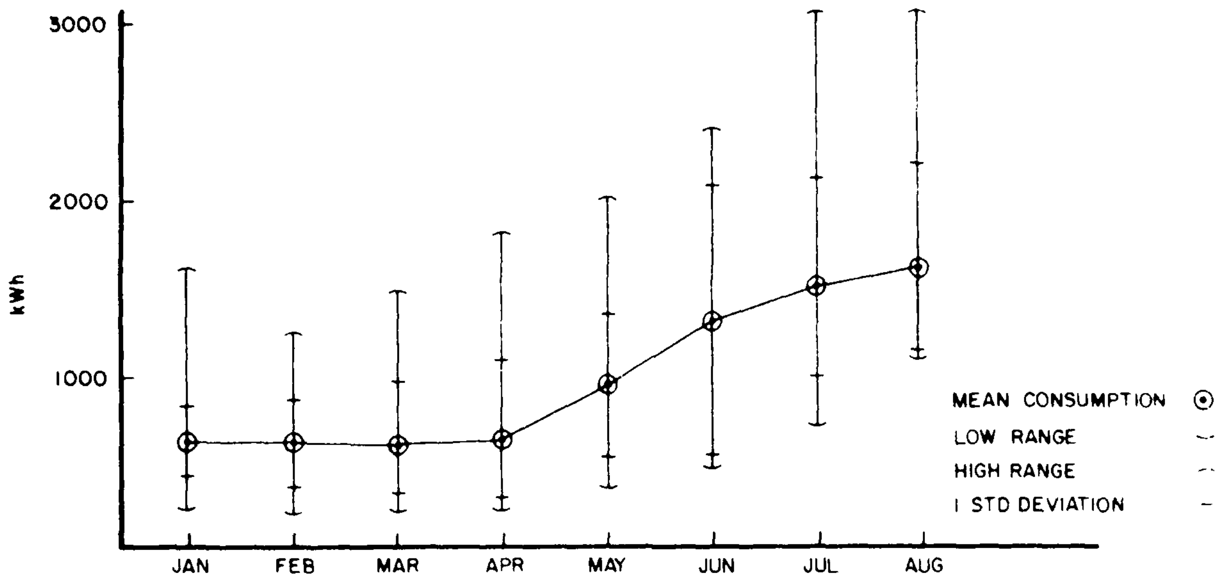

Figure 16. Family housing electrical consumption variation.

shows that family housing electrical consumption is highly dependent on the lifestyle of individuals occupying the house and on the equipment being used. Table 15 shows the range of electrical consumption (kWh/yr) for various major family housing appliances. The type and usage patterns of appliances, the climate, the number of occupants, and the building thermodynamic characteristics all affect electrical use in family housing.

Conservation or reduction of electrical energy use in military family housing depends largely on the occupants, so they must receive energy conservation information and guidance. In addition, electrical consumption can be reduced by limiting peak consumption through techniques that centrally control the operational periods of air conditioners, electric dryers, and water heaters if their use affects the installation demand billing periods. Control may be affected by such means as Frequency Modulation (FM) signals to receivers on the equipment, or by high-frequency power line carrier signals to receiving devices or over common telephone lines to end receivers. Some appliances, such as furnace fans, central air conditioners, refrigerators, and freezers are also good candidates for motor voltage controllers. Consideration should also be given to replacing ceiling incandescent and exterior incandescent lamps with higher efficiency lamps.

Electronic Time Switches and Load Controllers

Electronic programmable time switches and load controllers are relatively new on the market. Recent advances in microprocessors have produced small packaged units for multi-control functions. In their simplest form, the devices are digital electronic time clocks that can be used to control 1 to 20

Table 15

Family Housing Appliance Consumption

Appliance	kWh/yr	Appliance	kWh/yr
Refrigerator	700-2000	Television, color	400-600
Freezers	1200-2200	Television, black and white	100-200
Dishwasher	300-500	Humidifier	600-800
Range/Oven	800-1000	A/C, room	500-2000*
Clothes Washer	80-120	A/C, central	500-4000*
Clothes Dryer	900-1200	Water Heater	4000-6000
Furnace Fan	600-1000*	Clock	17.5
Lighting	1500-2500	Can Opener	0.2-0.3

*Approximate ranges -- highly dependent on climate, amount of use, and type of appliance.

different electrical loads through electric relays under as many different operating schedules. They are less expensive and are claimed to be more reliable than the often-used electrical/mechanical time clocks. Advantages of these systems are refined time accuracy, small size, long-term (24-hour) battery carryover, constant memory, and ability to control numerous loads from a single building location. The devices are easy to program initially or reprogram later to meet varying requirements. Although their long-term reliability has not been determined, it is expected to exceed that of the mechanical devices.

Load- and duty-cycle-oriented controllers provide a more sophisticated means of electrical load control. These devices can be used for loads that may need to operate under different or dual schedules. Options normally available on some systems can provide thermostatic override so that restarting will be based on a preset indoor or outdoor temperature or humidity condition. Additional options can shut off critical loads in the event of low voltage conditions, single phasing, or phase reversal, and automatically re-energize the devices when the fault is corrected.

A more complex and sophisticated approach to both electrical and thermal energy consumption control is use of an Energy Monitoring and Control System (EMCS). The EMCS is an energy management system that employs minicomputers, microcomputers, instrumentation, control equipment, sensors and software programs configured into a complete system. This system controls multiple functions in numerous buildings from a central point of operation and supervision.[12] From an electrical reduction standpoint, EMCS is a large-scale, multi-building application of time of operation scheduling, demand limiting, duty cycling and sophisticated HVAC control from a central location; it also provides feedback on equipment status.

Lighting Tests

Fluorescent lighting consumption of a single, two-lamp luminaire was measured in the laboratory to verify effects of high-efficiency lamps and ballasts. Table 16, which shows the results of these tests, indicates that high-efficiency lamps reduced energy consumption by roughly 25 to 30 percent. High-efficiency ballasts produced only a 3 to 6 percent reduction, but gave more light with high efficiency lamps than do high efficiency lamps with regular ballasts. Lighting levels were measured at 3 ft (0.9 m) perpendicular to the luminaire centerline. A dramatic decrease in power factor for luminaires was noted when lamps were removed, but the ballast remained energized. Nearly all the energy consumed by the ballast in this case

Table 16

Two-Tube Fluorescent Luminaire Test

Configuration	Energy (Watts)	Power Factor	Light Output (FC)
Regular Lamps and Ballasts	100	0.88-0.92	160
High-Efficiency Lamps and Regular Ballasts	73	0.80-0.85	140
High-Efficiency Lamps and High-Efficiency Ballasts	70	0.90-0.95	150
Regular Lamps and High-Efficiency Ballasts	94	0.88-0.94	145
Regular Ballast, No Lamps	8-12	0.10-0.30	--
High-Efficiency Ballast, No Lamps	4-8	0.08-0.30	--

[12] Energy Monitoring and Control System (EMCS) Large System Configuration, Draft CEGS-13947 (Department of the Army, Office of the Chief of Engineers, September 1980).

(4 to 12 watts) is reactive and lowers the overall building and installation power factor (see example, p 27).

An administration building at Fort Carson, CO, was chosen for a metered test of the energy-efficient fluorescent lamp in actual use. The building is a two-battalion headquarters and classroom building built in 1974. The single-story structure has a floor area of 18,770 sq ft (1744 m^2) with a partial basement of 3330 sq ft (309 m^2) that is used intermittently as a rifle range. The total connected lighting load for the building is 41 kW. All fluorescent luminaires in the building were relamped with energy-efficient lamps (Watt Misers). Figure 17 shows the metered effect of the relamping. The peak daily demand was reduced by 4 kW and overall electrical energy consumption was reduced by about 500 kWh per week. At a cost of $0.04/kWh, the savings would be $1040 annually. The area on the curve where relamped consumption is higher than that for the old lamp is caused by HVAC equipment operating at different times during the daily operation of the building. The energy-efficient lamps reduce total building electrical consumption by 10 to 12 percent.

Electronic Time Switch Test

The battalion headquarters and classroom building was also used for a metered test of an electronic programmable time switch (see Figure 18). The type of switch used can control four circuits with 10 separate programs and costs $300. The switch was used to control HVAC equipment in the building's mechanical room. Table 17 gives the connected equipment and schedule. The staggered on/off times were incorporated so that the switching could be observed and defined from the measured data.

The electronic time switch reduced consumption by 900 kWh per week, and at $0.04/kWh, will produce annual savings of $1870. The savings occur when the building is unoccupied. Figure 19, which illustrates the savings for a weekday, shows that the savings occur primarily during the night and reduce the weekday baseline (minimum) load from 17 to 11 kW demand. Figure 20 shows the effect of using the switch on weekends, where the difference in consumption and demand is more noticeable. Figures 21 and 22, respectively, show consumption before and after the 14-day period when the time switch was installed and indicate a reduction of 26 percent in the building's total consumption after installation. These curves also show a baseline demand reduction of 7 kW.

Table 17

Equipment Schedule

Equipment	Daily* On	Daily* Off
AHU #1 and CW Pump	6:00 a.m.	4:30 p.m.
AHU #2	8:00 a.m.	5:30 p.m.
Water Heater	7:00 a.m.	4:00 p.m.
HW Pump and AHU #2 Coil Pump	5:00 a.m.	4:00 p.m.

*Equipment programmed off on Saturdays and Sundays.

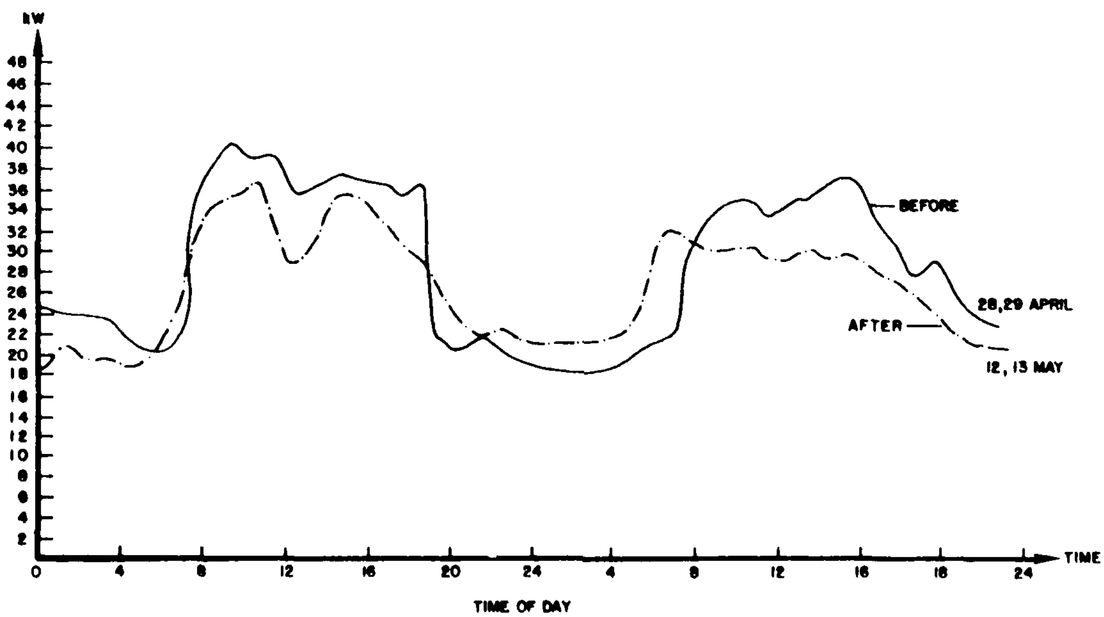

Figure 17. Effects of relamping test.

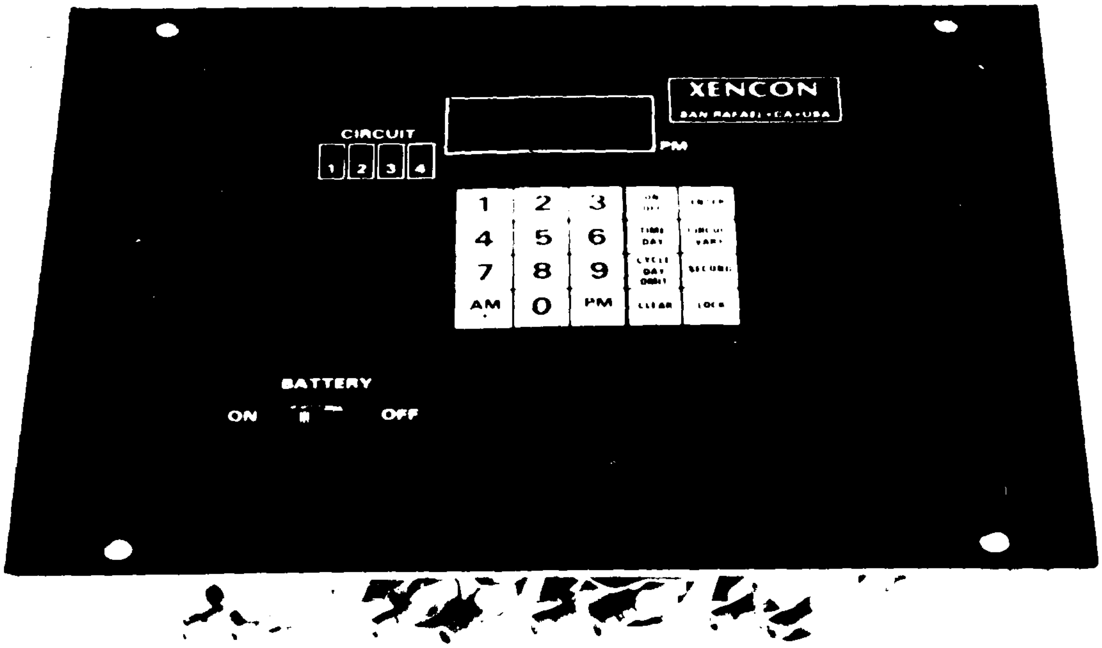

Figure 18. A time switch.

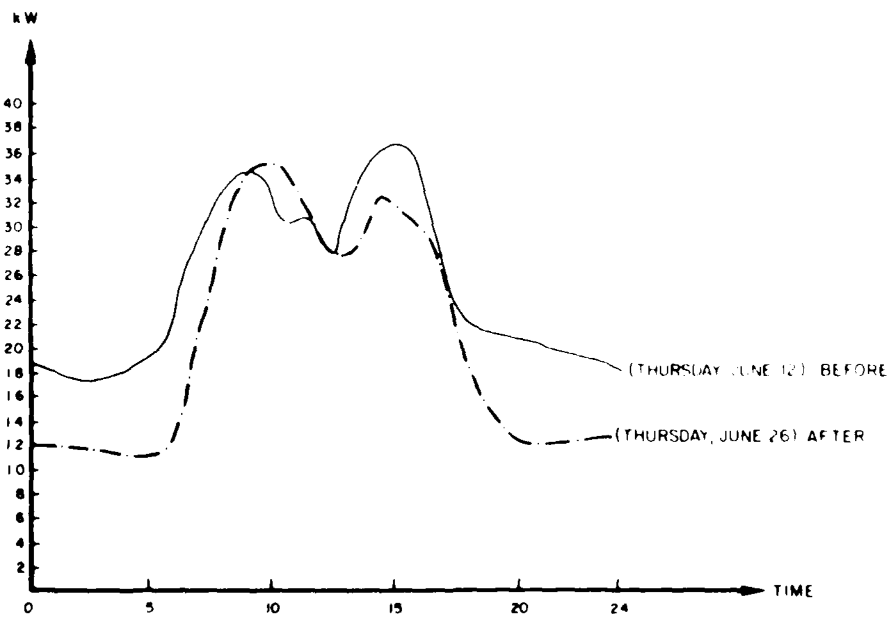

Figure 19. Effect of time switch -- weekday.

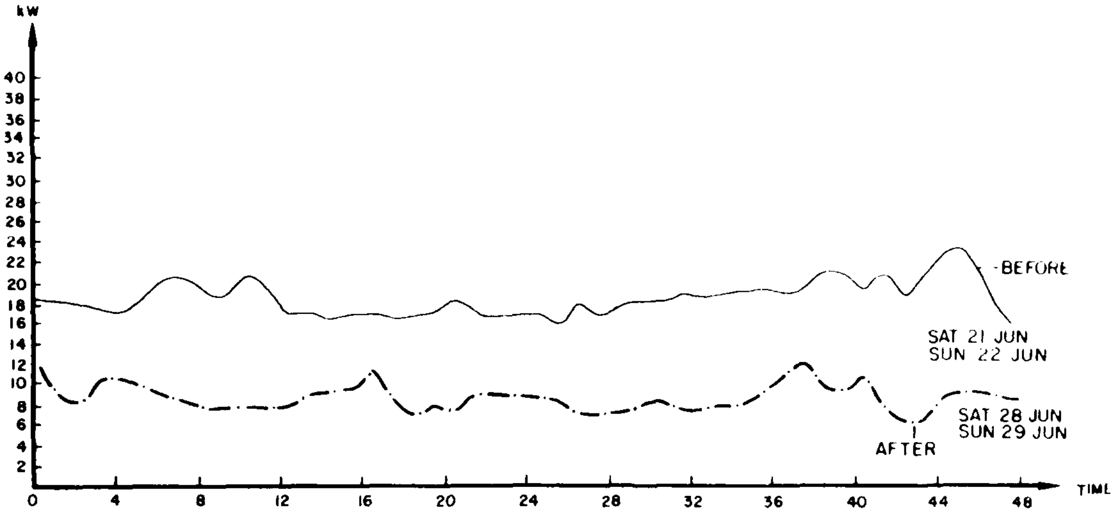

Figure 20. Effect of time switch -- weekend.

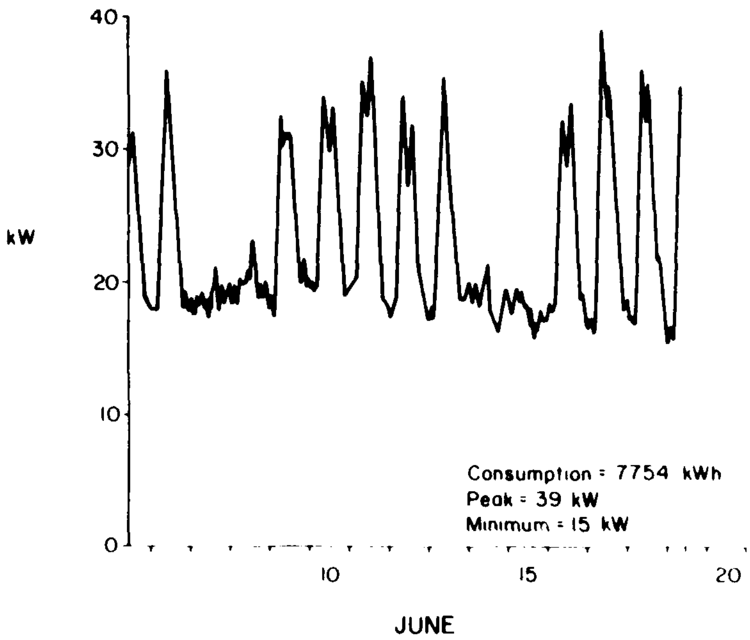

Figure 21. Before installation of electronic time switch.

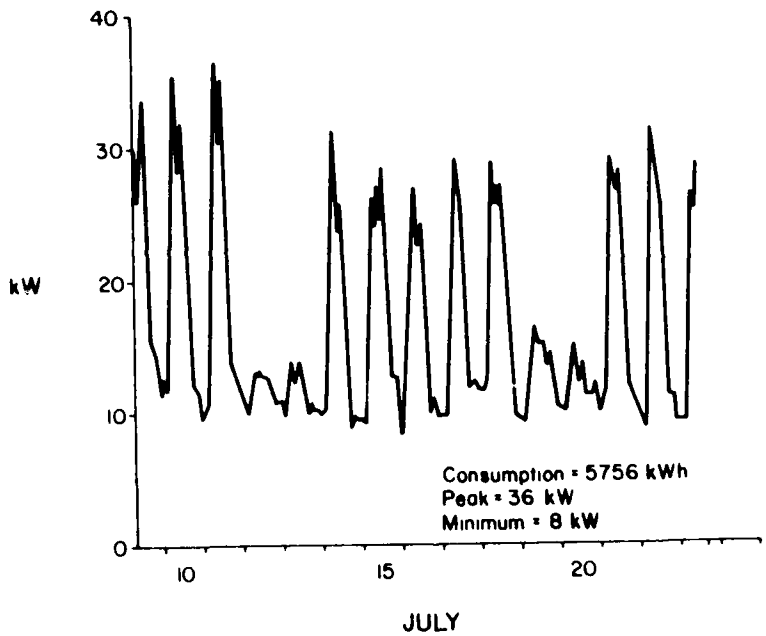

Figure 22. After installation of electronic time switch.

Power Factor

Power factor is the phase relationship between the current and voltage waveforms in an alternating current electrical system. Under ideal conditions, the voltage and current are "in-phase," and the power factor is 1.0 or unity, often expressed as 100 percent. If loads such as, but not limited to, induction motors, fluorescent lamp ballasts, transformers, or welders are present, power factors of less than 1.0 will occur. These inductive loads require work-producing current (active) and a magnetizing current (reactive). The reactive current performs no useful work, providing only the magnetizing force required for operating the device; however, the additional current must be carried by all system components (conductors, transformers, and switchgear) upstream of the load. The increase in total current, caused by the reactive component, increases the voltage drop in the system, causing performance to decrease in other electrical equipment, and causing increased heating in system components, which reduces their capacity to carry "work-performing" power. Distribution losses also increase since the reactive current must be carried by the distribution system (I^2r losses). As mentioned previously, utility companies sometimes assess penalties for low power factors, which can significantly increase some Army installations' electrical bills.

One common cause of poor power factors is using motors that are larger than necessary to drive individual loads such as fans and pumps. The reactive magnetizing current providing the force for motor operation remains virtually constant from no-load to full-load, but the power used to drive the load varies considerably from no-load to full-load. Therefore, lightly loaded motors operate at very poor power factors because the size of the reactive current component is large relative to that of the active current component. Poor power factor can also be caused by excessive use of low power factor lighting ballasts or ballasts that are left connected in a delamped fixture. To some degree, poor power factor can be forestalled by sizing motors as closely as possible to the load's actual horsepower requirements or by using a high-efficiency, high power factor induction motor. Most motor manufacturers now offer a line of high-efficiency/high power factor induction motors. The power factor can also be improved by cancelling the lagging component of inductive reactive current by means of an opposing leading reactive current to the applied voltage.

Synchronous motors can also be used to raise the power factor of systems. Sychronous motors are designed to have a unity power factor or a leading power factor where their use would offset the lagging reactive component of other system components. Static capacitor banks have replaced synchronous motors and condensers as sources of reactive kVA in most applications where the principal need is to supply leading reactive kVA's.

Capacitors offer the most practical means of improving the power factor on Army installations. They are versatile in application and therefore can be installed at any point of the installation's power system downstream of the utility company metering equipment (e.g., at the main substation, across the terminals of the load, or at any point in between, such as a motor control center or a distribution substation). Capacitors must be used with caution to avoid overcompensation (leading power factor) and misapplication (hoists). Capacitors are sold in a variety of modular units and in various kVAr (kilovar or kilovolt ampere reactive) ratings. They are passive devices (no moving parts) and can be installed at any convenient location that will minimize wiring costs. In effect, capacitors compensate for lagging kVAr on a one-to-one basis. For example, a 100-kVAr capacitor will cancel the effect of 100 lagging kVArs. Installing capacitors on the installation power system anywhere downstream of the utility companies' metering equipment will improve the overall plant power factor and thus reduce power factor penalty charges. Although capacitors can be connected at the load, the main substation, or at any point between, each option has separate economics and benefits. The nearer the load, the better the advantage, but also the higher the cost because of increased unit cost for smaller capacitors and increased cost caused by the lower voltage (larger physical size) of the computer. These must be thoroughly understood to determine the optimum point of connection. The FE must decide if all the benefits of power factor improvement are needed and will justify the high capacitor installation costs. The raw cost per kVAr of capacitors ranges from $3 to $100, depending on the voltage and the size of the capacitor being used.

Table 18 provides data that will help FE personnel evaluate power factor problems. The table provides kilowatt multipliers for determining the capacitor kilovars required for power factor correction. To use this table, enter the left vertical at the existing power factor; then move to the right along the row containing the original power factor value to the column containing the desired corrected power factor. The factor at this location multiplied by the kilowatt load on the system equals the kVAr of the capacitors required to obtain the corrected power factor.

Motor Voltage or Power Factor Controllers

A new device, invented at the National Aeronautics and Space Administration (NASA), has recently been advertised as a power factor controller to improve efficiency of existing motors. The invention was granted a patent in October 1977 and is owned by the U.S. Government; it is available to any manufacturer. This controller monitors the phase displacement between the applied voltage and the current drawn by an electric motor. The phase difference controls a triac semiconductor switch connected in series with the motor. This changes the duty cycle of the incoming waveform, somewhat like a silicon-controlled rectifier controls light dimmer functions. The effective input voltage is reduced at the expense of introducing switching transients into the supply lines. The basic concept behind this device is that a partially loaded motor does not require rated voltage to produce the required work, and that under these conditions, the effective reduced voltage reduces heat loss. This increases the efficiency of a partially loaded motor in comparison to that of a motor connected directly to the line. Even with the controller connected, the motor continues to run at almost its rated speed, since the input frequency remains the same.

Although the units have been tested and have been shown to provide significant power savings when a motor is not being used at its full load rating, several problems must still be resolved: (1) adverse effects the device may have on a distribution system caused by transients; (2) electromagnetic

Table 18

Capacitor Correction Factors
(kVA of Capacitors Required = Factor x kW Load)*

Existing Power Factor, Percent	Corrected Power Factor					
	100%	95%	90%	85%	80%	75%
50	1.732	1.403	1.247	1.112	0.982	0.850
52	1.643	1.314	1.158	1.023	0.893	0.761
54	1.558	1.229	1.073	0.938	0.808	0.676
55	1.518	1.189	1.033	0.898	0.768	0.636
56	1.479	1.150	0.994	0.859	0.729	0.597
58	1.404	1.075	0.919	0.784	0.654	0.522
60	1.333	1.004	0.848	0.713	0.583	0.451
62	1.265	0.936	0.780	0.645	0.515	0.383
64	1.201	0.872	0.716	0.561	0.451	0.319
65	1.168	0.839	0.683	0.548	0.418	0.296
66	1.139	0.810	0.654	0.519	0.389	0.257
68	1.078	0.749	0.593	0.458	0.328	0.196
70	1.020	0.691	0.535	0.400	0.270	0.138
72	0.964	0.635	0.479	0.344	0.214	0.082
74	0.909	0.580	0.424	0.289	0.159	0.027
75	0.882	0.553	0.397	0.262	0.132	
76	0.855	0.526	0.370	0.235	0.105	
78	0.802	0.473	0.317	0.182	0.052	
80	0.750	0.421	0.265	0.130		
82	0.698	0.369	0.213	0.078		
84	0.646	0.317	0.161			
85	0.620	0.291	0.135			
86	0.594	0.265	0.109			
88	0.540	0.211	0.055			
90	0.485	0.156				
92	0.426	0.097				
94	0.363	0.034				
95	0.329					

*Recheck at low load condition to insure leading power factors are not obtained.

interference (EMI); and (3) changes in motor life. Whether this motor controller actually changes or improves the power factor is difficult to define because the motor controller reshapes incoming voltage waveforms. However, the voltage and current to the motor are reduced; therefore, both the active and reactive power components are reduced. These reductions will positively affect the total building's power factor in relation to the overall building reactive power requirement.

Alternating Current Synthesis (ACS) is an electric power conversion technique invented at the Massachusetts Institute of Technology in the early 1970s by Mr. R. H. Baker. It uses power transistors to switch direct current (dc) electricity sources -- such as batteries or rectified utility power -- to produce a synthetic ac waveform. The frequency and voltage of the ac waveform can be varied and controlled to match the requirements of standard electric motors, which can then be effectively operated at variable speed.

There are two basic ways to employ ACS devices. Since ACS is essentially a technique to switch and resynthesize dc power, it is possible to start with dc sources such as batteries or solar cells. The discrete blocks of dc power are then appropriately reconfigured in the ACS to manufacture an ac output waveform of variable voltage and variable frequency. In this fashion, one experiment demonstrated the capability to use conventional ac water pumping machinery with energy supplied by solar photovoltaic panels.

The other, more common, way to employ ACS devices is to begin with fixed voltage, fixed frequency utility supplied power, rectify it with conventional means into dc power, and then resynthesize it in the ACS device to variable voltage, variable frequency ac power. Several ACS units have already demonstrated this capability in air handling and liquid pumping applications.

Since 1976, ACS has been the subject of intensive development at the Electric Power Conversion Systems Venture of Exxon Enterprises Inc. There are now over 30 engineering professionals and technicians working on the development, improvement, and application of ACS devices. Although other "inverter" techniques are available to generate variable voltage, variable frequency ac waveforms, none are known to approach the efficiency, reliability, cost effectiveness, weight, and volume advantages of ACS.

A key advantage of this technique is the elimination of iron filters and transformers. In conventional equipment, magnetic (iron) components are used to reshape crude waveforms into something resembling a sinusoid. These components result in equipment which is heavy, expensive, inefficient, and at best, imperfect. With ACS, the waveform is accurately synthesized digitally, thus eliminating the need for additional waveform optimization. The result is significant reduction in equipment size and cost as well as significant improvement in efficiency.

Alternating current motors have always been considered fixed-speed devices; that is, when energized directly from the fixed voltage and fixed frequency electricity supply of a utility, the rotating speed of an alternating current motor is essentially constant no matter what the load demand is. By providing excitation from an ACS device, it becomes possible to effect significant energy savings by running this normally fixed-speed machinery at the optimum speed demanded by the load.

This variable speed capability can result in energy savings up to 50 percent in typical industrial process applications.

Applications

There are many possible applications for these devices, since almost any electric motor of up to 400 hp is a candidate. The salient point in determining the best application is the requirement that the motor be part loaded (i.e., <75 percent) for a significant portion of its operational time. This is important because the greatest savings occur at part load. Knowing which motors are running at part load and the degree of the partial loading is sometimes difficult. This information may be obtained either by measurements or analysis. Calculations must be performed incorporating the power consumption, run time, and estimated savings created by application of the device. At this time, the manufacturers' test data are the only savings data available.

The best and most accurate measurement is of the motor power factor; this can be done using a power factor meter which attaches to the motor terminals. A three-phase power factor meter costs between $1000 and $2000. Either post personnel or contractors can take the measurements. (This added labor expense must be considered when determining the economic feasibility of installing power factor controllers.)

Analysis, while not as accurate as direct measurement, will probably be less expensive. Some examples of possible applications, as determined by analysis, are presented below. In general, these devices are effective in high use, variable load, or lightly loaded motors.

1. Pumps. Many pump motors are oversized because of the past practice of insuring that the motor nameplate rating would not be exceeded by the pump brake horsepower at any point on the pump curve. The best candidate pumps will be those which operate under variable flow rates. Application should be considered on variable-volume, hot- or chilled-water system circulating pumps, condenser water circulating pumps, and condensate or boiler feed water pumps.

2. Fans. Any fan where the volume of air handled varies is a good candidate for power factor controllers (e.g., fans in variable volume systems with inlet vane or damper control). Fans on air-cooled condensers are also good candidates.

3. Compressors. Compressors may often operate at part load for various reasons. Depending on the type of compressor unloading, the motors may use a power factor controller or other device. On reciprocating compressor motors, the power factor controller may be useful when suction valve lift, cylinder head bypass, or back pressure valve capacity reduction is used. However, the control would not be useful when hot gas bypass is used, because the compressor load is not reduced. Power factor controllers may be applied to centrifugal compressors with variable inlet vanes or suction damper capacity control.

Time Switches

A problem arises when energy managers depend on equipment operators to switch the motors. In some cases, individuals do not know when equipment may be turned off and still not interrupt building operations. There are also situations when the timing of "turning a load off" becomes critical in terms of obtaining maximum savings. A modern scheduling device (i.e., an electronic programmable time switch) has several channels which can be separately programmed for different on and off times during one or several days.

Scheduling is the automatic turning on and off of several loads so that they are only on when needed (e.g., plugging a coffee maker into a preset alarm clock so that the coffee will be ready at a specified time). Many actual situations in buildings are uncontrolled and therefore waste energy. A scheduling device -- used for fan motors, pumps, exterior lighting, and exhaust fans -- can help relieve this situation.

Another way of controlling motors is by duty cycling -- turning loads on and off at a fixed rate to achieve only a percentage of total on-time. The time period of each cycle is very short (5 to 30 minutes) when compared with scheduling. Ventilation fans are an excellent application for duty cycling. Many of these are over-designed for the room or building where they are used since new ventilation criteria have been issued. Thus, they can easily be cycled without any loss of effectiveness. However, some larger motors should not be cycled too frequently. Some manufacturers recommend their motors not be restarted more than one or two times per hour.

6 CONCLUSIONS

Most electricity consumed by Army installations is for lighting, heating, air conditioning, ventilating, appliances, and motors.

A large percentage (50 to 70 percent) of total annual electricity consumption is attributed to the magnitude of the minimum baseline consumption (lowest hourly demand/consumption). The baseline is attributed to HVAC fans and pumps that operate continuously.

Daily and seasonal electrical demands depend on climate, season, type of building, and the habits and lifestyles of building users.

Reducing overall energy use and demand on Army installations will reduce the energy, fuel adjustment, and demand penalties often incurred by large power consumers.

Use of more efficient equipment will reduce electrical consumption as well as demand, and will reduce the overall electricity expenditures by increasing the power factor. This will have substantial impact on the installation's utility bill.

Electronic programmable time switches can be used to schedule the operation of major electricity consumers, such as HVAC equipment; they provide a viable and economical method of eliminating continuous consumption, and thus often reduce the baseline consumption by as much as 60 percent and overall building consumption by as much as 30 percent. When economical, electronic programmable time switches in conjunction with override thermostats in cold climate should be applied to schedule HVAC equipment.

An analysis of installation utility bills for past years will reveal the sources of electrical expenditures and show whether savings are more readily available from energy conservation, demand limiting, or power factor correction.

Army installation electrical energy consumption can be substantially reduced (10 to 30 percent) by applying techniques such as time scheduling of equipment and reduced energy for lights at the same or reduced light levels.

Motor voltage controllers (power factor controllers) can be effectively used on many Army motors to reduce motor operating costs by as much as 40 percent. Motor voltage controllers (power factor controller) should first be used in several noncritical applications such as HVAC fans and pumps to determine their reliability and applicability. Their application and use should be carefully monitored to obtain operational and reliability information. Only those used successfully by other consumers should be tried.

The variability in family housing electrical consumption of identical units indicates major differences in occupant use of energy; therefore, continued emphasis should be placed on energy conservation education and awareness. The use of demand-limiting switches (controlled by radio signals or time switches) is recommended for equipment such as central air conditioners, electric dryers, and electric hot water heaters.

A survey of each Army building (using Figure 23) will help determine the electrical equipment installed, operating hours, and special requirements. An analysis of each building survey will provide a basis for scheduling start and stop times for equipment and will allow the FE to determine the potential for electrical energy reduction in the areas of lighting or equipment scheduling.

A major pitfall in motor replacement is oversizing, which causes excessive power consumption and a poor power factor. If high-efficiency motors are used in new and replacement situations, motor operation efficiency can increase by 5 to 8 percent.

Modification of existing inefficient or ineffective lighting systems can reduce lighting energy consumption significantly (up to 50 percent). Lighting surveys and effective design of lighting modifications are essential to obtain optimum savings and still maintain adequate lighting. High-efficiency fluorescent lamps should be used in most relamping situations. The installation should compare the economics of either complete relamping or replacing lamps upon burn out whenever the age of existing lamps (more than 8 years) indicates high failure rates. High-efficiency ballasts will usually not be economical because replacement is labor-intensive and there is a low savings (3 to 6 watts/hr); however, these should be used to replace failed ballasts.

The best way to reduce electrical energy consumption is to emphasize automatic scheduling control or cycling of HVAC motors and the use of more efficient lighting systems. HVAC equipment generally is the major contributor to the baseline consumption in a building because it often operates continuously. The FE must know how much electricity each component uses and the length of time it operates to determine savings created by scheduling. Detailed building-by-building surveys will determine actual operational and occupancy requirements, connected equipment and equipment/appliance usage, and corresponding consumption. An analysis of electrical utility bills which isolates energy, demand, and power factor penalty costs may suggest more efficient operational or equipment use techniques, such as peak shaving or demand limiting if demand charges are high, or power factor corrections if the power factor charge is high. Analysis should be done as shown in Tables 2 and 3.

Bldg. No.______
Type______________

Lighting -- Interior and Exterior

Type	Location or Use	Light Level (Foot-Candles)	Number of Fixtures	Watts Per Fixture	Est. Monthly Hours On	Calc. Monthly Consumption (kWh)
					Lighting Total	

$$\frac{\text{Number of Fixtures X Watts/Fixture X Hours of Use}}{1000} = \text{Consumption (kWh)}$$

Motors -- Include All HVAC Fans, Pumps, and Exhaust

Use	Location	Horse-power	Volts and Phase	Full Load Amperage	Power Factor	Est. Monthly Hours On	Calc. Monthly Consumption (kWh)
						Motor Total	

Single Phase: $$\frac{\text{Volts X Amps X Power Factor X Hours of Use}}{1000} = \text{Consumption (kWh)}$$

Three Phase: $$\frac{\text{Volts X Amps X Power Factor X 1.732 X Hours of Use}}{1000} = \text{Consumption (kWh)}$$

Figure 23. Electrical survey form.

Other Equipment and Appliances
(Include water coolers, water heaters, vending machines, etc.)

Electrical Device	Volts	Amps	Watts	Number of Devices	Est. Monthly Use (Hours)	Calc. Monthly Consumption* (kWh)

Equipment Total ________

* If motors, use formula on previous page, otherwise

$$\frac{\text{Volts X Amps X Hours of Use}}{1000} = \text{Consumption}$$

or

$$\frac{\text{Watts X Hours of Use}}{1000} = \text{Consumption}$$

Lights ________
Motors ________
Equip. ________

Building Total ________

Normal building occupancy

Number of occupants _____
Hours of occupancy _____

Explain special requirements:

Figure 23. (Cont'd).

Checklist for Energy Misuse (circle one)

Exterior:

Are lights on during daylight hours? Yes/No
Exterior lights are presently controlled manually/by timers/by photocells?
Are windows open during HVAC operation? Yes/No
Are doors blocked open during HVAC operation? Yes/No
Indicate general condition of sealing, caulking, and weatherstripping:

Windows	good/fair/poor
Doors	good/fair/poor
Other penetrations	good/fair/poor

Note and record outside air temperature at time of survey ____ ^oF
Other problems noted during exterior survey.

Interior:

Lights being used when not needed

Work Areas	Wattage of Lamps on
Offices	
Day Rooms	
Corridors	
Closets	
Mech. Rooms	

Are large area room lights switched to allow partial use? Yes/No
Specifics:
Are fluorescent fixtures delamped to reduce light level to 50/30/10 foot-candle? Yes/No
If not, indicate problems.
Have ballasts in delamped fixtures been disconnected? Yes/No
Are temperature restrictions (65 winter/78 summer) being maintained? Yes/No
Check setpoint of representative sample of thermostats. Record below.
Measure temperature of room near thermostat. Record below.

	1	2	3	4	5
Are thermostats of the limiter type? Yes/No; setpoint temp.	__				
Do thermostats incorporate night setback? Yes/No; measured temp.	__	__			

Figure 23. (Cont'd).

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